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Minimizing vehicular traffic via optimized land use development for a sustainable and equitable future

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ABSTRACT

MINIMIZING VEHICULAR TRAFFIC VIA OPTIMIZED LAND USE DEVELOPMENT FOR A SUSTAINABLE AND EQUITABLE FUTURE

by
Babu Veeregowda

Mixed-use developments and transit-oriented developments are becoming very common in urban areas in an effort to reduce sprawl. Numerous studies have shown that such programs would not be successful unless the mix of land uses and sizes is well-balanced and integrated with the surrounding neighborhood. Developers often ignore this aspect in favor of immediate financial gain and do not realize that there are sustainable financial benefits in land use optimization. In addition, professionals often work with limited logistics, resources, and technical knowledge and therefore struggle in setting goals and suggesting land uses that have less auto dependency based on travel demand characteristics.

The current traffic impact assessment methodology (part of the environmental review process for approval of a project) is one-dimensional. It does not consider land use optimization based on the surrounding neighborhood characteristics that have a significant effect in reducing vehicular traffic. These surrounding neighborhood characteristics are often grouped into categories reflecting the “D’s of development”—Density, Diversity, Design, and Distance to transit—and would have significant benefits in minimizing auto dependence.

The objectives of this research are to first develop a methodology to optimize the mix of land uses and sizes to minimize the number vehicular trips and maximize the person trips using a case study of a mixed-use development. This will help to further understand the travel demand and parking behavior. Secondly, this research will use the travel demand

characteristics from other approved mixed-use developments from various boroughs of New York City with diverse neighborhood characteristics to validate the land use optimization methodology. The third and ultimate objective of this research is to develop a model that is practical and implementable on a regional level to optimize the mix of land uses and sizes based on localized travel behavior patterns and neighborhood characteristics to minimize vehicle trips. In this study, a genetic algorithm has been developed and tested on one development to demonstrate its application (objective 1) and is subsequently applied to additional developments (objective 2). A stepwise regression analysis is then performed to develop equations for the optimal number of vehicle trips as well as the percent split of individual land use types within a development, all based on the surrounding neighborhood characteristics (objective 3). The research results in a series of equations that can be used to optimize a development's mix of land uses and sizes by minimizing vehicular trips and maximizing person trips. Although the equations vary from city to city, the methodology is adaptable enough such that planning agencies can generate their own equations for their own region and engineers can then use them to forecast trips.

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by
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I dedicate this research to my mother Sarojamma.

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CHAPTER 1

INTRODUCTION

1.1 Overview

For most urban commuters in America, traffic congestion has become a challenge to endure on a regular basis during their morning and evening commutes. Congested roadways exert private costs in wasted time and fuel, social costs from increased travel times for all commuters, and environmental costs through the release of pollutants and greenhouse gass emissions into the atmosphere. The private cost of traffic congestion has risen exponentially over the last several decades, increasing nearly fivefold since 1982 to a total of $124 billion in 2013, which is expected to increase by another 50% by 2023 (Guerrini, 2014).

While environmentalists and decision makers debate the value of spending money on infrastructure improvements or “smart” development to ease traffic congestion, engineers and planners still have a challenge to address the traffic congestion. Many communities across the U.S. have implemented various “smart” development programs such as congestion pricing, higher density development, context-sensitive development, transit-oriented development, and mixed-use development within the context of urban conditions as ways of alleviating traffic congestion. However, research has shown that none of the above “smart” programs can become successful unless a land development happens with a “balanced or optimized” mix of land use and size that are mutually conducive, beneficial, and apply the principles of Four D’s to the surrounding urban context (Hamid, I. et al., 2014) (Handy, 2005). “Smart” developments that are sensitive to the surrounding context, using the principles of these Four D's, would reduce generated traffic and provide enormous benefits to the environment, safety, neighborhood, health, and the unnecessary need to build additional infrastructure to mitigate impacts. Numerous studies and available evidence suggest that a well-integrated mix of land uses and sizes with the surrounding built environment and "smart" development programs can reduce peak period traffic at many sites by as much as 10% to 15% (Meyer M. D. et al., 2001). Further, several studies indicate that a development with an optimized mix of land uses and sizes can reduce driving dependency by 20% to 40% (Bartholomew, K. et al., 2009). Despite these research findings, there are limited guidelines for prescribing a methodology for selecting development alternatives that are balanced and optimize the mix of land uses and sizes that limits the vehicular demand while maintaining a high number of person trips attracted to the development, thereby ensuring economic success. The *Institute for Transportation Engineers (ITE) Trip Generation Manual*, which is in use in most jurisdictions nationwide for travel demand forecasting, assumes a 95% auto mode share and assumes single-use developments (Currans, 2017).

1.2 Current Land Use Impact Analysis Practice and its Shortfall

Today's traffic impact studies' methodologies are tailored to a single use, stand alone, highway-oriented, suburban type of development. These methodologies are similarly applied to mixed-use, integrated, transit oriented, and infill developments, and these traffic studies consequently overlook the benefits of the alternative land uses, nor do they optimize the mixes of land uses and sizes. Consequently, the studies impose unreasonable obstacles to appropriate planning and approval of smart growth. In addition, the traffic impact guidelines do not provide for assessing the benefits of alternative land uses or optimizing the mix of land uses and sizes on the development, surrounding neighborhood, or transportation network. It is very important to assess the benefit of optimizing the mix of land uses and sizes by evaluating the development itself along with the surrounding neighborhood and public transportation network. Optimized mixed-use developments with high internal trip capture that integrate urban design as part of the development program and support non-motorized modes, such as walking and bicycling, would have a huge impact on reducing congestion.

In addition, today's traffic impact study guidelines and criteria that support "smart" development are static and one-dimensional. They do not emphasize on types of land uses in which the trips are internalized within the development among various uses, land uses that are high transit oriented/friendly, and a development design that supports non-motorized trips such as walking and bicycling. A study suggested that "smart" growth, mixed-use developments, and transit-oriented developments will not reduce auto dependency unless the land uses are optimized in a manner that encourages walkability and transit usage as well as with existing neighborhood characteristics (Handy, 2005). As a result, most communities are forced to live with non-smart developments and associated environmental impacts.

Furthermore, land development projects tend to have numerous stakeholders such as investors, nearby residents, representatives from nearby businesses, elected officials, decision makers from various agencies, environmental advocacy groups, and many others with various interests and agendas (the "stakeholders"). Hence, it is essential to develop an optimized set of land uses from which an alternative can be selected that is equitable to all stakeholders.

In order to create an optimized mix of land uses and sizes through the core principle of "smart" growth, it is important to understand the travel demand characteristics of various land uses such as the daily person and vehicular trip generation rates, temporal distributions, modal splits, internal linkages, and vehicle occupancies. These factors are highly dependent on the neighborhood characteristics and contribute to the Four D's of planning principles. For example, if there is a good public transportation system, a residential land use would tend to attract more person trips via the public transportation system as opposed to destination retail or convention center land uses. However, in order to meet the goals of the stakeholders, one may need land uses that may not be advantageous from a local context perspective. Nevertheless, the goal of the "smart" development can be met by optimizing the mix of land uses and sizes in a manner that is sensitive to the surrounding neighborhood character.

Many optimization techniques are available in the literature to assist in developing an optimized mix of land uses and sizes such as linear programming and multiple regression. Based on an extensive literature review, it was concluded that most of these commonly used optimization techniques will perform well as long as the requirements are linear, structured, and efficient only when one single objective is clearly identified (Stewart et al., 2004). However, a global search for a heuristic method such as the genetic algorithm (GA) is capable of fully exploring the multi-objective parameters of Integrated Land Use (ILU) and provide sets of alternative numbers of Pareto-optimal solutions or land uses from which various professionals such as planners, engineers, investors or developers can make a collective decision (Srinivas & Deb, 1994), (Kesur, 2009), rather than offering a single "best" solution. In these research studies, the authors have introduced a methodology to develop a set of alternatives with optimal land use solutions using the GA. Although a substantial number of studies and papers have been reported in land use "spatial" optimization using the GA, a heuristic optimization method for finding the best mix of land use and size that is context sensitive and has low environmental impact has not been thoroughly investigated before in the land use and transportation literature. This dissertation will assist professionals and agencies significantly when making decisions that are based on smart growth.

1.3 Overall Approach to the Research

The research studies in this dissertation are organized as follows:

As described above, Chapter 1 presents a review and identifies key shortfalls in the current environmental impact assessment methodology in terms of transportation during land use selection.

Chapter 2 will assess and consider factors for estimating travel patterns, land use and its contributions to chronic urban congestion and environmental impacts, and the necessary improvements to overcome current shortfalls.

Chapter 3 will investigate traffic impact analysis practices and examine if there are any ILU developments to meet the goals of New Urbanism and neo-traditional planning which focus on smart development by integrating context sensitivity to minimize the size of auto-dependent land uses. This literature review will help to understand the current land use optimization techniques and their strengths and weaknesses, the best optimization techniques for multi-objective parameters, and heuristic optimization techniques using the GA. It will also investigate the various factors influencing land use planning while considering traffic congestion and sustainable development and choose important objectives to be considered for multi-objective optimization.

Chapter 4 will outline the process using the GA for optimization of land uses and sizes by taking the various parameters of context sensitivity into consideration to meet the needs of neo-traditional planning goals. It will also formulate the process of modeling landscapes as an optimization process wherein spatial configurations are created through the use of evolutionary algorithms in the form of a Pareto set.

Chapter 5 will expand on Chapter 4 to include additional conditions and show how to use the results of the GA to obtain an optimized mix of land uses and sizes.

Chapter 6 will discuss the implications of the research done in Chapters 4 and 5 as it relates to qualitative and quantitative changes in the number of vehicle trips, size of each land use, and parking implications.

Chapter 7 will validate the findings of Chapter 6 by performing the GA analysis in numerous other projects within New York City that were selected for a diversity of land use densities, access to public transportation, and neighborhood services.

Chapter 8 will apply the results from Chapters 6 and 7 in order to create universally adaptable equations that can be used to generate optimized vehicle trips based solely on neighborhood characteristics. The Statistical Package for Social Sciences (SPSS) is used to perform stepwise regressions of vehicle trips for each land use type (residential, neighborhood, destination, office) with respect to various neighborhood characteristics.

Chapter 9 will provide a summary of the research and recommendations for future researchers.

CHAPTER 2

PROBLEM IDENTIFICATION

2.1 Introduction

The congestion issue described in Chapter 1 has forced urban planners, transportation engineers, and elected officials to contrive innovative ways to minimize the adverse impacts on air quality, travel time, health, and safety within the urban environment. At the state and local levels, the planning doctrine known as New Urbanism or neo-traditional planning (Tachieve, 2010) has grown in popularity as a response to the call to minimize congestion using various sustainability measures such as congestion pricing, smart growth, mixed-use developments, and transit-oriented developments (TOD) to reduce auto dependency (Mullin, 2010).

In recent years, there seems to be a lack of interest among local planning authorities towards new land developments, rezoning, and urban renewal plans to maintain the existing traffic volumes and environmental conditions. This "no development" approach results in stagnating economic growth in the region (Todara et al., 2003). Across the nation, planning departments and zoning boards have made progress in controlling urban sprawl (Burchell and Listokin, 1995), (Fulton, 1996), a major contributor to auto dependence and the resulting congestion, by promoting various forms of sustainable developments as explained above. Although there are stringent environmental review processes required at the local level for approval of a land development, rezoning, or urban renewal project, not enough emphasis is currently placed on sustainable developments that rely on the available public transportation systems or assets and non-vehicular modes of transportation.

The current traffic impact assessment practice (part of the environmental quality review process towards an approval of a project) is stagnant and one-dimensional in that only one build scenario is evaluated without examining the optimization of the mix of land uses and sizes to minimize auto dependence. Also, there are many land developments that are constructed as-of-right and do not require an extensive review or study for project approval. Consequently, there are no incentives or required evaluations of alternative build scenarios that exploit existing public transportation infrastructure to lower automobile-dependent land uses. There is a lack of direction to regulate or optimize the mix of land uses and sizes in a manner that exploits the existing and surrounding public transportation systems, maximizes person trips while reducing auto trips through smart land use selection, and incorporating urban design that is conducive to walking, biking, and transit. The lack of incentives from local governments toward efforts involving sustainable development has contributed to developers avoiding building such developments. Furthermore, there is a serious lack of tools and techniques for optimization of the mix of land uses and sizes.

2.2 Current Land Development Environmental Practices and Shortfalls

Conventionally, land development progresses from an architect selecting land uses and submitting to an environmental review which evaluates and discloses impacts to the surrounding area. While transportation engineers are consulted during the environmental review process, their input is not sought during the actual land use selection process. The input and feedback from the transportation consultants is critical as they can study the existing infrastructure meticulously, identify available resources, and, hence, avoid significant adverse impacts. The transportation engineer's input will help to determine the best methods for minimizing automobile trips while maximizing person trips and address key issues such as traffic congestion. The current trial-and-error methodology to optimize the mix of land uses and sizes either to avoid adverse impacts or build an integrated development is inherently cumbersome, time-consuming, costly, and an optimal outcome is rarely achieved. In addition, there are many cases in the past in which developers and/or investors had to abandon land development projects in the middle of the environmental review process as a result of the high cost of mitigating adverse impacts or when the return on investment decreases due to the loss of valuable land to parking, storm water management, or open space requirements. Therefore, a new tool during the initial planning stages that optimizes the mix of land uses and sizes in a manner that minimizes vehicle trips while maximizing person trips is needed to find the best land use development envelope (Foytic et al., 2011).

2.3 The Need for a Land Use Optimization Tool from a National Goal Perspective

The United States has an ambitious goal of reducing carbon dioxide (CO_2) emissions by 60% as of 2050, relative to 1990 levels. Several publications have demonstrated that the United States transportation sector cannot do its fair share to meet this target through vehicle and fuel technology alone. Transportation associated CO_2 reduction is viewed as a three-legged stool, with one leg related to vehicle fuel efficiency, a second to the carbon content of fuel itself, and third to the amount of vehicle miles traveled (VMT). Numerous studies and available evidence suggests that well-integrated and aggressively promoted vehicular demand reduction programs can reduce peak period traffic at many sites by as much as 10% or 15% (Litman, 2016), (Meyer et al., 2000). The study "*Is Smart Growth*

Associated with Reductions in Carbon Dioxide Emissions?" found that a well-integrated mixed land use development that complements the surrounding neighborhood character and transportation assets would reduce vehicle travel and tailpipe emissions by 9% (Wang et al., 2013). A detailed review of research "*Draft Policy Brief on the Impacts of Land Use Mix Based on a Review of the Empirical Literature, for Research on Impacts of Transportation and Land Use-Related Policies"* concluded that the elasticity of vehicle travel with respect to optimized mix of land use and size is -0.02 to -0.11 (a 10 % increase in an entropy or dissimilarity index reduces average VMT 0.2% to 01.1%) (Spears et al., 2010). It was also found that optimized mix of land use and size reduces vehicle travel and significantly increases walking (Ewing & Cervero, 2010). The report "*Carbonless Footprints: Promoting Health and Climate Stabilization Through Active Transportation"*, found that the per capita vehicle travel and pollution emissions tend to decline as optimization of the mix of land uses and sizes increases; for example, shifting from the 25th percentile to the 75th percentile level of mix reduces total VMT to 2.7% (Lawrence et al., 2010).

2.4 Usefulness and Real-World Application

Although there are numerous research studies in land use optimization or allocation at a regional level, none have been conducted on developing a methodology to optimize the mix of land uses and sizes at a local level or single project by taking advantage of the surrounding neighborhood characteristics and public transportation assets. In addition, there are no guidelines that prescribe a methodology to limit the vehicular demand while maintaining a high number of person trips to a large-scale mixed-use development in an urban setting, thereby ensuring minimal environmental impacts and maximum economic success. Such a methodology is urgently needed by transportation professionals and real estate developers to identify an optimized mix of land uses and sizes based on the surrounding neighborhood character. This results in additional linked trips between the land use based on a smarter mix of land use within the development and cross-sharing of parking between land uses to take advantage of different peak periods. In going through this process, the developers' financial needs are ensured by limiting the impacts of a development on traffic, parking, transit, and pedestrians, and helping to make the development more sustainable and equitable. This research will demonstrate that it is possible to meet such needs while maintaining economic success, minimal environmental impact, and a sustainable development.

2.5 Exploration of Techniques for the Research: A General Discussion

Based on the review of various publications and as briefly discussed earlier in the Introduction in this Chapter and later in detail in the Literature Review in Chapter 3, many papers have already been written describing the benefits of using genetic algorithms (GA) or other heuristic methods over error methods which are currently used for environmental reviews (Paul et al., 1998). Since the GA is a global search heuristic method, it is useful in fully exploring various transportation demand elements of the surrounding built environment and providing a set of alternative optimal solutions. Various professionals (planners, engineers, investors, and developers) can select their most preferred option based on potential transportation and environmental impacts (Srinivas & Deb, 1994), (Kesur, 2009), rather than selecting the architect's only option which ignores potential adverse impacts. The outcome of this research will also encourage policy makers and decision makers at various agencies to incorporate an integrated and optimized mix of land uses and sizes into growth management or traffic impact policies as part of the local development approval process. It further motivates the developer to incorporate the urban design or to build alternative transportation modes and/or service friendly development by better linked trips together with the surrounding transportation system.

CHAPTER 3

LITERATURE REVEIW

3.1 Introduction

Land development, rezoning, and urban renewal have become complex processes since they involve multiple and usually conflicting demands from the stakeholders. These objectives may be unstructured and thus difficult to handle. Within this context, several computer-based techniques are available to assist city planners and engineers with decision making. In this Chapter, previous studies, and research related to reducing the number of vehicle trips in a mixed-use development, as well as research related to multi-objective function optimization, will be reviewed and summarized to understand their applicability, usefulness, strengths, weakness, its relevance to optimizing the mix of land use and size based on travel demand characteristics of the surrounding built environment. Section 3.2 will provide an overview into attempts to accommodate the phenomenon of mixed-use developments using traditional methodologies. In Section 3.3, various optimization techniques and their strengths and weaknesses, in the current methodology, pertaining to the mix of land use and size are discussed. Section 3.4 will summarize the concept of the genetic algorithm (GA) optimization process used for developing a methodology to overcome some of the shortfalls and to address real world issues in optimizing the mix of land use and size. Section 3.4 will also discuss the foundation for this research toward developing an appropriate methodology to optimize the mix of land uses and sizes that is critically needed by the industry.

3.2 Attempts to Correct for Mixed-Use Developments

There have been several attempts to account for phenomenon of mixed-use, “smart” growth, and transit-oriented developments by creating models that generate vehicle trips based on varying neighborhood characteristics. Bochner et al. developed a proposed revision to the *ITE Trip Generation Manual* which provides linked trip credits between various land uses within a mixed-use development (Bochner et al., 2010). It was partially incorporated into the *ITE Trip Generation Handbook;* its *3rd Edition* has a mixed-use development procedure (ITE, 2017). This proposed revision was generated by conducting interviews with travelers at three mixed-use developments around the country and developing origin-destination matrices based on the data. Limitations of this methodology include the following:

1. Land uses are limited to residential, office, local retail, hotel, and cinema/entertainment. These are very specific and may not be included in all mixed-use developments, especially the hotel and cinema/entertainment uses.
2. The model does not use neighborhood characteristics to generate an optimized mix of land uses and sizes.

Gulden, Goates, and Ewing created “the MXD model” which uses neighborhood characteristics including residential and non-residential land use area, total residential dwelling units, intersections within one mile of the development, household income, median household income, and employment within one mile of the development, employment within a 20-minute automobile commute, employment within a 30-minute automobile commute, employment within a 30-minute transit commute, and employment within the entire region (Gulden e. al., 2014). These neighborhood characteristics are used to calculate trip reduction factors which can then be applied to ITE Trip Generation Manual models. This model has several limitations. These limitations include the following:

1. It cannot be used for developments larger than 7 million square feet.

2. It uses ITE Trip Generation Manual equations to generate standalone vehicle trips before applying trip reduction factors. Therefore, it assumes a specific mix of land uses and sizes that may not be optimal.

3. The trip reduction factors focus around trip purpose and not land use optimization.

3.3 Current Optimization Practices and Their Strengths/Weaknesses

The linear programming (LP) model is commonly used in the traffic engineering industry for such tasks as route optimization to reduce travel time and optimization of signal timing and phasing plans to reduce queue delay, emissions, spillback, etc. The LP model was first developed in the 1960s to solve linear or quadratic equations that address problems in urban planning systems (Guldmann, 1979), (Aerts et al., 2003). However, the LP model is efficient only when a single objective is clearly identified (Stewart et al., 2004). The LP model does not complement many travel demand parameters of the neighborhood character such as the public transportation system and travel demand characteristics by land use, trip linkage, or internal capture rate among various land uses, nor does it account for modal split nor integration of transit and pedestrian friendly design. It is, furthermore, insufficient for complex land use optimization situations because multiple objectives are involved such as providing enough affordable housing per local legislation, reducing traffic congestion, preserving the environment, maintaining certain sizes for certain land uses, etc. Because the LP model cannot handle nonlinear and unstructured requirements like interactions between land uses and sizes, it is not suitable for a complex integrated land use optimization problem.

As a result, the GA, which is capable of handling unstructured urban issues, was proposed in the 1970s (Hopkins, 1977), (Los, 1978). The GA is a type of general global heuristic optimization algorithm, and it has been shown to be robust and efficient for searching large, complex, and little understood search spaces such as those of multi-objective land use planning problems (Zhang et al., 2010). Furthermore, because the GA works with population plans and allows for the generation of a number of Pareto-optimal solutions within a “single” Pareto-optimal front, planners can choose from a set of alternative solutions (Srinivas & Deb, 1994), rather than one “best” solution.

It was discovered during this research and initial analysis that the biggest drawback of this technique was the optimization of large scale developments which typically have numerous mixes of land uses and sizes and their interwoven relationship with the travel demand parameters of the surrounding neighborhood character. A single Pareto-optimal front solution with numerous sets of alternatives can become very cumbersome and confusing especially when transportation planners and engineers deal with the public and elected officials who are not well versed in this field (Beasley et al., 1996). The GA provides a pool of “good-enough” solutions instead of providing a smart solution based on the travel demand characteristics that can be easily understood and ready to implement. For the non-technical person who lacks the training of a traffic engineer, it will be difficult to determine which one solution out of the pool of good-enough solutions within a “single” Pareto-optimal front would be the best. In short, with the GA, no one solution sticks out as the clear winner.

As part of this research, the author discovered a hybrid technique whereby a complex optimization of the mix of land use and size can be solved by incrementally building series of simplistic steps by using travel demand and its relationship with land use but with “multiple” Pareto-optimal fronts for best alternatives and executing the model in a series of "individual" bounds (land use mixes) and variances (sizes) using a perturbation-iteration method. This hybrid technique provides an opportunity to bundle various travel demand factors within the framework of multi-objective function optimization, in such a way that a single objective function can be formed and analyzed using the perturbation-iteration technique for various bounds and variances. This technique will further assist the analyst to communicate simply but pragmatically with stakeholders, including those who are non-technical. In fact, several researchers have applied GA in various instances to solve multi-objective non-land use related problems to a single objective solution using various parameters and constraints so that meaningful outcomes have been achieved (Balling et al., 2004), (Cao et al., 2012), (Chandramouli et al., 2009), (Ligmann-Zielinska et al., 2008), (Matthews, 2001), (Matthews et al., 2006), (Stewart et al., 2004). This approach is well-suited for today's many challenges in land use optimization. The new model that has been developed as part of this research is discussed in detail in Chapter 4.

Much of the current scholarly literature written about the regional or local land use optimization strategies focus too much on objectivity and optimization techniques without considering the Four D's of land use planning. Although numerous techniques such as the GA (Balling et al., 2004); (Cao et al., 2011), GIS (geographical information systems) (Batty et al., 1999), (Wang et al., 2004), and DSS (computer-based decision support system) techniques (Matthews et al., 2006) have been proposed as solutions to land use optimization for regional and local planning land uses, rezoning, and urban land renewal purposes, they overlook the travel demand assessment and its regional and local impacts. Some of the above research has been done to rezone and abide by the Urban Land Renewal Act formation at a local level. However, attention to the matter of smart growth, integrating land uses and sizes, and trip making characteristics based on the surrounding neighborhood character for which optimization could be conducted is lacking. In this research, a land use optimization model, based on the GA, is proposed to overcome the shortcomings of the past studies and lack of research and methodology.

As of late, the GA has been found to be suitable enough to tackle the aforementioned problems (Aerts et al., 2005). In sharp contrast to other heuristic approaches including those discussed earlier, GAs are wide-ranging search procedures with universal applicability, meaning that they are not restricted to a particular discipline. The GA is a form of evolutionary computation developed by John Holland in 1975. Although GAs are found to be robust tools that can produce exceptional results for multi-objective function optimization problems (Goldberg, 1989), they can become cumbersome, complex, time consuming since they give multiple solutions. The GA is rooted in the principles of natural selection and evolution. Land use problems typically involve large solution spaces and are computationally complex as multiple iterations are required. GAs are capable of generating optimal solutions in a computationally efficient manner. By the 1980s and 1990s, since a vast majority of multi-objective genetic algorithms (MOGA) were hard to ascertain, many planners and engineers started employing the GA instead.

From the very rudimentary stages, MOGA approaches have focused on the generation of a set of Pareto-optimal solutions (Pareto, 1896). The major elements involved in the GA process are summarized as follows: survival of the fittest, crossover, and mutation (Beasley et al., 1996). The 'survival of the fittest' step ensures that the best solutions are selected for the next generation. Crossovers occur by methodical swapping of values among solutions, and mutations occur by randomly changing the values within a solution. A more detailed discussion of these steps is presented in the subsequent section.

3.4 Genetic Algorithm

In order to understand the strength and weakness of the GA in the land use optimization problems discussed above, it is important to understand how the GA works. As noted above, the GA is a heuristic search and optimization technique that mimics the theory of evolution. GA follows the principle of "Select the best, discard the rest." Thus, GAs implement the optimization strategies by simulating evolution of species through natural selection. A simple GA is represented in Figure 3.1.

The three operators and parameters of Genetic Algorithm are as follows:

1. **Selection**: The process that determines which solutions are to be preserved and allowed to "reproduce" and which ones "die out". The primary objective of the selection operator is to emphasize the good solutions and eliminate the bad solutions in a population while keeping the population size constant and addressing the principle of "Select the best, discard the rest."

2. **Crossover:** The crossover operator is used to create new solutions from the existing solutions that are available in the mating pool after the selection. This operator exchanges the gene information between the solutions in the mating pool. The most popular crossover selects any two "parent" solution strings randomly from the mating pool and some portion of the strings' "DNA" is exchanged between the strings. The selection point is selected randomly. Figure 3.2 shows the crossover process.

3. **Mutation:** Mutation is the occasional introduction of new features into the solution strings of the population pool to maintain diversity in the population. Though crossover has the main responsibility to search for the optimal solution, mutation is also used for this purpose. Figure 3.3 shows an example of mutation.

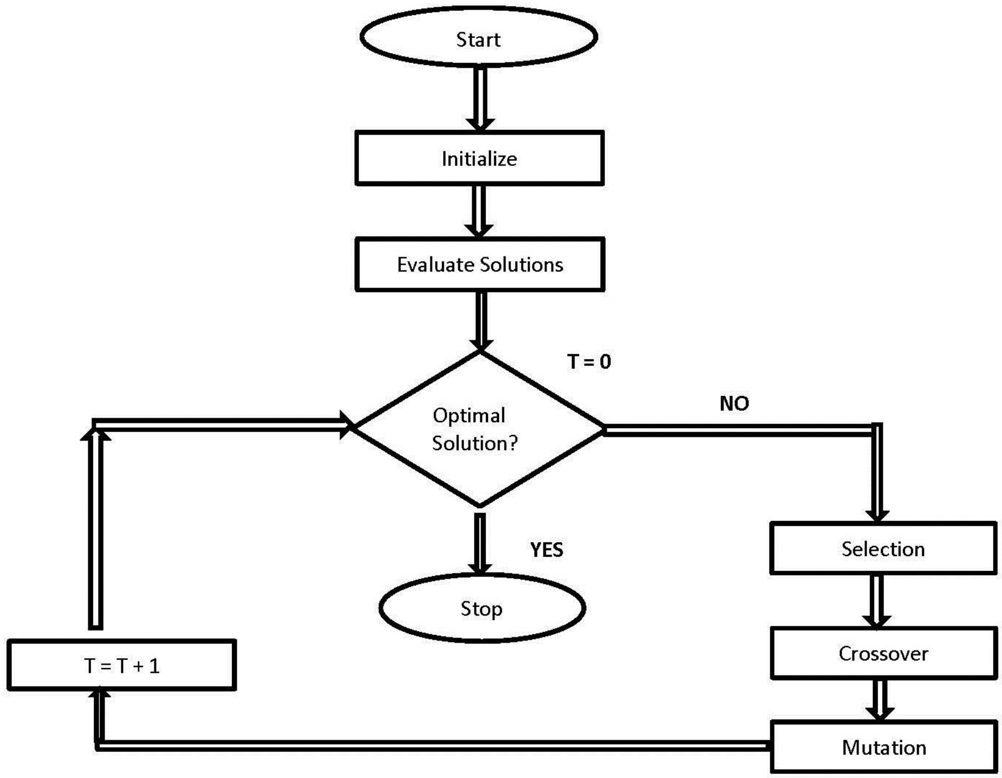


Figure 3.1 Flow chart of a simple genetic algorithm. The GA is an iterative algorithm that repeats itself until the optimal solution is reached. In each iteration, the "fittest" solutions are selected and crossovers and mutations are performed to preserve diversity in the solution set.

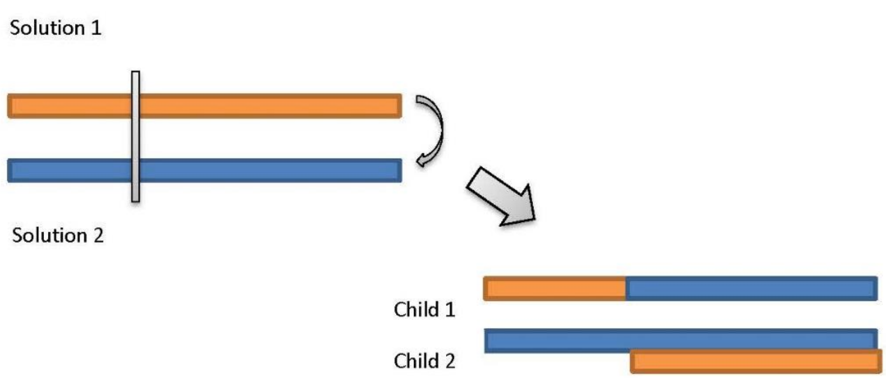


Figure 3.2 An example of a crossover. The "parent" solutions on the top left exchange a portion of their "DNA" to create "child" solutions as shown at bottom right.

Figure 3.3 An example of a mutation.

The GA applies the principles of evolution found in nature to the problem of finding an optimal solution. In a GA, the problem is encoded in a series of bit strings that are manipulated by the algorithm; in an "evolutionary algorithm," the decision variables and problem functions are used directly.

An evolutionary algorithm for optimization is different from "classical" optimization methods in several ways:

1. **Random versus Deterministic Operation**: An evolutionary algorithm relies in part on random sampling. This makes it a nondeterministic method, which may yield somewhat different solutions on different runs, even if the model is not changed.

2. **Population versus Single Best Solution:** Where most classical optimization methods maintain a single best solution, an evolutionary algorithm maintains a population of candidate solutions. Only one (or a few, with equivalent objectives) of these is the "best" solution, but the other members of the population are "sample points" in other regions of the search space, where a better solution may later be found. The use of a population of solutions helps the evolutionary algorithm avoid becoming "trapped" at a local optimum, when an even better optimum may be found outside the vicinity of the current solution.

3. **Creating New Solutions Through Mutation:** Inspired by the role of mutation of an organism's DNA in natural evolution, an evolutionary algorithm periodically makes random changes or mutations in one or more members of the current population, yielding a new candidate solution (which may be better or worse than existing population members). The purpose of mutation is to add diversity to the solution set. There are many possible ways to perform a mutation, and the GA software actually employs three different mutation strategies. The result of a mutation may be an infeasible solution, and the GA software attempts to "repair" such a solution to make it feasible; this is sometimes, but not always, successful.

4. **Combining Solutions Through Crossover:** Inspired by the role of sexual reproduction in the evolution of living things, an evolutionary algorithm attempts to combine elements of existing solutions in order to create a new solution, with some of the features of each "parent." The elements (e.g. decision variable values) of existing solutions are combined in a "crossover" operation, inspired by the crossover of DNA strands that occurs in the reproduction of biological organisms. As with mutation, there are many possible ways to perform a crossover operation, some much better than others and the GA software actually employs multiple variations of two different crossover strategies.

5. **Selecting Solutions Via "Survival of the Fittest"**: Fifth, inspired by the role of natural selection in evolution, an evolutionary algorithm performs a selection process in which the most “fit" members of the population survive, and the "least fit" members are eliminated. In a constrained optimization problem, the notion of "fitness" depends partly on whether a solution is feasible (i.e. whether it satisfies all of the constraints), and partly on its objective function value. The selection process is the step that guides the evolutionary algorithm towards ever-better solutions.

3.5 Outline of the Research

Based on the literature review and the immediate needs of the industry, this methodology was formulated to optimize the mix of land uses and sizes based on the travel demand assessment of the surrounding neighborhood character. To validate the methodology that was developed in this research, the Willets Point Development, a major mixed-use development environmental impact statement (EIS), that was sponsored and recently approved, was used as a case study. Chapters 4-6 will analyze this case study using the GA. In Chapter 7, this methodology will be expanded to other projects around New York City in order to validate the results of the case study. Chapter 8 will take the results of Chapter 7 and apply regression models to create equations for vehicle trips as a function of neighborhood characteristics. Chapter 9 will provide a summary of the research, recommendations for implementation of the methodology, and recommendations for further research.

CHAPTER 4

METHODOLOGY FOR OPTIMIZING THE MIX OF LAND USES AND SIZES

4.1 Introduction

Chapters 1 and 2 have emphasized the need for immediate actions to reduce the adverse impacts of land development through sustainability at the local level to have a greater impact at all levels—local, regional, national, and eventually global. At the local level, the biggest challenge is the optimization of the mix of land uses and sizes based on travel demand that is sensitive to the surrounding neighborhood character and reduces automobile dependency while maximizing economic activity. Chapter 3 discussed some of the optimization techniques that are commonly used in the industry, including the GA, and their shortfalls, especially concerning the lack of studies and research on land use optimization. These chapters laid the foundation to develop a methodology to optimize the mix of land uses and sizes in a manner which is useful for the industry.

For decades, stakeholder groups across the nation and around the world, worked to develop policies, programs, and incentives such as tax breaks, other subsidies, fee waivers, and area bonuses to manage regional and urban growth and promote the use of public transportation systems. Early on, it was realized that there is more value to applying the concepts of sustainable development at the local level in an effort to minimize urban sprawl, traffic congestion, environmental impacts, and compliance with national goals such as reducing greenhouse gas emissions by a certain year. As a result, both the United States and the United Kingdom have formulated various programs and initiatives to accomplish such goals at the local level.

In the 1990s, sustainable development programs were adopted such as mixed-use development, transit-oriented development, and “smart” growth. (Duany, 1991), (Calthrope, 1993). These programs had the same goal of reducing automobile dependency.

After years of ideological discussions about the above goals and issues and numerous initiatives and programs, a consensus has been reached that the reduction in auto dependency is more relevant and urgently needed for urban areas since it generates the vast majority of both vehicular and person trips. Managing urban growth will not only address the burning environmental issues as discussed in Chapters 1 and 2, but will also address many other challenges such as urban sprawl, increases in vehicle miles traveled (VMT) and vehicle hours traveled (VHT), and spending on infrastructure in outlying areas. This makes sense especially since over half of the world’s inhabitants—3.9 billion people— live in urban areas (United Nations, 2014). By 2030, 60% of the world population, almost five billion people, will be city dwellers (Strøbæk, 2014). This prognosis calls for urgent rethinking of planning and design solutions. Also, several surveys of millennials show that there is an acute demand for housing that is non-automobile dependent. The millennials expect to reside in live-work-play environments that represent a single convenient location with a short commute to work and a healthy community that provides biking, walking, and transit facilities (Regional Plan Association, 2016). This has created a huge demand for mixed-use developments in urban settings as well as non-automobile dependent developments such as transit oriented development.

Today, 20% of the developments are mixed-use and market analysis shows that this trend will continue (Niemira, 2007). Hence it is very important to develop a methodology to review and approve a land use development project that takes into account lower demand for automobiles. As mentioned above, the current land use developments are based on economic returns on investment rather than sustainability. The objective of this research is to meet both needs—to create a methodology that considers the sustainability and the profitability of a project.

It is critical to understand the factors that affect the trip generation and traffic pattern of a mixed-use development based on the travel demand characteristics of the surrounding built environment. Both vehicular and person trip generation for any land use is dependent on various characteristics such as types of land uses and its sizes, the Four D's of density, diversity, design, and distance to public transportation system, internal trip linkage among various land uses within the development, and urban planning features of the proposed development such as friendlier sidewalks and the ability of the internal and external roadway network to accommodate transit such as bus shelters, bus lanes, turning radii, and more. The smart and effective way to reduce automobile dependent development is hinged upon selecting the right mix of land uses and size in conjunction with the surrounding neighborhood character while satisfying the competing interests of the stakeholders. This is a great challenge to meet.

In a mixed-use development, especially a large-scale one, it becomes impossible for planners to search through and analyze all the possible land uses that are equitable from both smart growth and sound financial return on investment perspectives. In fact, it is even impossible to consider a significant fraction of the universe of possible plans from the smart growth perspective. Very often, planners or architects select a mix of land uses and sizes based on the overall scale of a project and visual perspective in accordance with the input from investors or developers. By the time it gets to the transportation planners and engineers, the decisions are made and there is no opportunity for suggestions on smart growth development. This is unfortunate because such plans are usually selected by an ad hoc process that may not necessarily generate the best plan.

This research will demonstrate the benefits of having a transportation planner or engineer work side by side with urban planners and architects so that he or she can facilitate an informed decision-making process by drawing upon the knowledge of tools for the optimization of the mix of land uses and sizes. This research will develop a methodology whereby sets of optimal land use plans will be developed to assist in selecting the optimal mix of land uses and sizes using the GA and regression analysis. It is based on trip generation characteristics of various land uses, the minimization of automobile dependency or trips, and the maximization of person trips, and neighborhood characteristics.

4.2 Development of a Real Estate Economic Model

The economic success of a mixed-use development is based on the ability to attract people or increase person trips. In developer's terms, a development which attracts the same number of person trips with fewer automobile trips compared to the initial area is considered a "smart" development. The mixed-use development is a boon in many ways since it meets the goals of New Urbanism, the various initiatives of local and national agencies and environmental groups, stringent air quality policies, and the minimization of environmental impacts.

However, mixed-use developments are financially risky for investors compared to single-use developments (Rabianski, 2007). In order to investigate these risks, four real-estate trade associations – BOMA International, the International Council of Shopping

Centers (ICSC), the National Association of Industrial and Office Properties (NAIOP) and the National Multi Housing Council (NMHC) – jointly surveyed their respective memberships to understand and assess a broad spectrum of problems and opportunities for mixed-use developments. This landmark co-sponsored survey established a new working definition for mixed use. The results of this survey along with some background on the history of this product type — which today accounts for about 20% of all new space built in the United States — are further discussed below.

Almost 60% of the real estate industry players and observers who participated in the survey suggested that choosing an optimal mix of land uses and sizes is their biggest challenge (Rabianski, 2007). From the developer's perspective, more automobile-dependent land use implies more parking and less developable area or less opportunity for sharing of parking with other land uses. The developer also sees the dollar signs in cost intensive traffic mitigation improvements, impact fees, additional storm water management, maintenance cost, and more. According to the cross-agency survey, 97% responded that most developers are willing to vary land use sizes from 5% to 50% of their sizes as part of the initial area to minimize vehicle trip generation (Rabianski, 2007).

4.3 Research Impetus – General Background

As noted above, in an economy-driven market, real estate developers and private land owners are driven by profit-making objectives. They often disagree with industry professionals, agencies, environmentalists, and the general public about the optimization of land uses and sizes. Traditional government regulations (e.g., density zoning, purchase and transfer of development rights, financial incentives/disincentives for certain kinds of development, regulatory and educational approaches) that encourage socially beneficial land development are, unfortunately, inadequate for dealing with the interests of the stakeholders.

After an extensive literature review, it was found that there are many studies, methodologies, applications, and approaches that are available for solving the complex land use allocations at a regional, state, and municipalities/township levels. Some of the studies that have been done (Bochner et al., 2010), (Gulden et al., 2014), (Aerts and Heuvelink, 2002), (Berke and Godschalk, 2006), (Jiang-Ping and Qun, 2009), (Ligmann-Zielinska et al., 2005), (Stewart et al., 2004) have commonly dealt with objectives like maximizing land use compactness, improving compatibility among neighboring land uses, ensuring suitability of land units for land uses, identifying per capita demand for land uses, identifying ways to generated linked and internal trip rates, and so on. However, to the best of the author's knowledge, there is no methodology available for optimizing the mix of land uses and sizes in conjunction with neighborhood characteristics and the ability to generate alternatives to a "status quo" development to reduce automobile dependency.

4.4 Purpose and Aim of the Research

Trip generation for land development is a function of several factors – the type and size of land uses which influence both automobile and person trip rates, the surrounding neighborhood character which influences modal split and linked and internal trip rates. The aim of this research is to develop a quick and efficient technique by using the GA and linear regression to determine the optimal mix of land uses and sizes in combination with surrounding neighborhood characteristics to take advantage of neighborhood characteristics which would result in the development of a trip generation profile to minimize the automobile dependency and environmental impacts. This would be a major step towards various state and national programs and initiatives to reduce environmental impacts. In addition to minimizing automobile dependency, the other aim of the research is to find a path of least resistance for environmentalists and citizens, whose primary interest is to minimize automobile dependency, and for investors, whose primary goal is to increase the attractiveness of a development to generate more person trips. This research will use a large-scale, mixed-used development that was approved by the NYCEDC to quantify the environmental benefit of this methodology through a GA analysis and compare it to what was approved. Similarly, in addition to assessing the environmental benefit, the research will assess the economic benefits. The research will then expand to other developments around New York City and use regression analysis to develop a set of equations that generate vehicle trips based entirely on neighborhood characteristics.

4.5 Development of a Mix of Land Use and Size Optimization Technique

The organization of this land use optimization technique consists of five sections:

- **Section 4.5.1:** General Theory and Role of Optimization;
- **Section 4.5.2:** Evaluation and Suitability of Single- and Multi-Objective land use optimization;
- **Section 4.5.3:** Software Used for this Research; and
- **Section 4.5.4:** Development of a Land Use Optimization Model Using a Single Objective Function.

4.5.1 General Theory and Role of Optimization

Life is full of daily optimization problems. What mode of transportation to take to save time and money? Which car should be bought with the best fuel efficiency while minimizing the price? Optimization is fine-tuning the inputs of a process, function, or device to find the maximum or minimum output(s). The inputs are the variables and constraints, the process or function is called the objective function or fitness function and the output(s) is fitness or cost (Haupt et al., 2004). This research relies on the optimization model for the decision-making process because it provides a quantitative assessment of the effects of the surrounding neighborhood character which influences trip generation on mixed-use developments.

The multi-objective problem can be formulated into a single objective problem by redesigning the problem into a single primary or higher order function with constraints. For example, the objective of a mixed-use development of increasing density while reducing automobile trips and traffic congestion, is inherently conflicting. The densification of a development implies an increase in automobile trips, hence increasing traffic congestion and air quality impacts. However, a single objective problem can be designed in such a way that it optimizes the land use types and its corresponding sizes while generating less automobile dependency and subsequently less traffic congestion and air quality impacts (this will be further explained in Section 4.5.2). The aim of the optimization process can be expressed as follows:

$$min/max\ f(x) = y = (f_1(x), f_2(x) \ldots f_n(x)) \tag{4.1}$$

Conditional on

$$C(x) = (C_1(x), C_2(x) \ldots . C_m(x)) \tag{4.2}$$

where n is the number of objective functions and m is the number of constraints.

In the above expressions, the decision vector x is equal to (x_1, x_2...x_n) and the objective vector y is equal to (y_1, y_2...y_n). The set of values (x_1, x_2...x_n) ϵ x signifies the decision space and the set of values (y_1, y_2...y_n) ϵ y represents the objective space. The feasible set of solutions is determined by the set of constraints i.e. $C(x) \leq 0$.

In this research, realization of the objective is tackled by deploying mathematical functions that correspond to maximizing the person trip generation and minimizing vehicular trip generation. Therefore, all of the problems and functions in the GA analysis are addressed as minimization problems.

4.5.2 Evaluation and Suitability of Single- and Multi-Objective Land Use Optimization

Chapters 1 and 3 present various optimization techniques that are used in the industry including the appropriateness for selecting the GA. Section 3.1 explains the strengths and weaknesses of single- and multi-objective optimization techniques, the core of the GA, as well as the usefulness of each technique in optimizing the mix of land use and size. The important conclusion from the literature reviews and these preliminary results is that too many variables are involved in setting objectives and constraints for optimizing the mix of land uses and sizes to provide realistic solutions which would make the model computationally intractable, more narrowly defined, cumbersome, and, as a result, less useful (Gabriel, 2006). Therefore, efforts have been made to produce computationally tractable solutions by using the single objective function of the GA (Aerts et al., 2005), (Haque and Asami, 2011), which is more robust, capable of generating feasible alternatives, and deals with different conflicting objectives. More importantly, many aspects of this research are focused on developing a single optimal solution but most of the stakeholders are interested in multiple "best" solutions that result in less auto-dependent land use development.

Furthermore, a multi-objective optimization technique could become intractable for enumeration techniques for large mixed-use developments. This is because of the exponential growth of the problem size with the increase in number of discrete decisions (that is, the dimension of the problem), or the so-called curse of dimensionality. The search for a solution in such a multi-dimensional space quickly becomes lost in the wealth of space when the dimensionality becomes too large. Therefore, in order to avoid these intricacies and overcome the shortfalls of both single-objective and multi-objective optimization techniques, this research developed a model using the travel demand characteristics for the large-scale mixed use development such as the Willets Point Development whose goal is to find the multiple "best" solutions of minimizing vehicular trips to reduce the environmental impact, maximizing the person trips to reduce the suburban sprawl (core principle of the smart development) and increase accessibility and profitability, and maintaining the same total development area as the initial area to meet the principles of urban land renewal.

4.5.3 Software Used for this Research

Mathworks' MATLAB is used to program the GA for multi-objective optimization. Statistical Packages for Social Sciences (SPSS) is used to perform the regression analysis required to generate the equations of vehicle trips as functions of neighborhood characteristics.

The GA is programmed using MATLAB version 7.1. The choice of this software for genetic programming was greatly influenced by the simplicity and flexibility of the MATLAB programming and its capability to handle large number of iterations. MATLAB is an interpretive language designed for handling voluminous numerical computations. MATLAB's numerical calculations can be performed and the results can be visualized without tedious programming efforts.

The linear regression is performed using SPSS. This software is used in statistical analysis and can perform correlations and various regressions tests such as f-tests, means variance, and t-tests.

4.5.4 Development of a Land Use Optimization Model Using a Single Objective Function

After a review of various optimization models, algorithms, and their strengths and weaknesses, it was concluded that the best methodology suited for this research is the single objective function using the GA. To achieve the goal of this research, the author adopted simple and intuitive objectives and constraints that are not cumbersome or difficult to formulate in mathematical terms, applicable in the real world situation, and ready to use in the industry, and easy to understand by all stakeholders.

4.6 Objective Function

Based on the research and initial run of the optimization model and as described in Section 4.5.2, for the purpose of this research, it is determined that it would be appropriate to use single-objective optimization, i.e., minimize the number of total vehicle trips generated by the mixed-use development. This can be done effectively by strategically linking the trip generation characteristics of each land use in conjunction with other land uses while keeping the fundamental phenomenon of the single-objective optimization in mind. The following steps summarize the process that was adopted that would lead to the formulation of the model to accomplish the goal of the research.

Any optimization problem has three major components: objective functions, variables, and constraints. There can be multiple functions, variables and constraints depending on the type of problem. The notation of optimization also implies that there are some functions that can be improved but can also be used as a measure of effectiveness of the design.

The objective function, $F(x)$, also known as the fitness function, measures the effectiveness of the design. This function might be a formulation of a single objective $f(x)$ or multiple objectives. For this research, the objective function is to minimize vehicle trips and is as follows:

$$min(Z = Vehicle\ Trips) = \sum_i \sum_j S_{ij} X_j \tag{4.3}$$

Where Z = Total vehicle trips, S_{ij} = Average vehicle trip rate for vehicle type i and land use j, and X_j = Area of land use j.

4.7 Variables

The potential of change is expressed in terms of ranges of permissible changes of certain design variables and is denoted by a vector:

$$\mathbf{x} = \{x_1, x_2, \ldots . x_n\} \tag{4.4}$$

The design variable can be either continuous or discrete. A continuous variable is one that takes any value in the range of the variation in its region. A discrete variable is one that takes only isolated values, typically from a list of permissible values. Therefore, these design variables can be expressed as:

$$x = (x_1^T, x_2^T, \ldots x_J^T) \mid j = 1, 2, \ldots J \tag{4.5}$$

$$x_{ij} \, \varepsilon \, D_i, D_j = (d_{j1}, d_{j2} \ldots \ldots d_{j\lambda}) \tag{4.6}$$

The vector of design variables **x** is divided into *J* sub–vectors $\mathbf{x_J}$. The components of these sub–vectors $\mathbf{x_{ij}}$ take values from a corresponding catalogue $D_{i,}D_{j,}$ and indicate the number of design variables in each sub–vector, and λ is the number of sections in each catalogue.

In addition to the variables listed in Section 4.6, the following additional variables were input into the GA:

- S'_{ij} = Average person trip rate for trip type *i* and land use *j*;
- W_j = Total vehicle trips per unit area on land use *j*;
- W'_j = Total person trips per unit area on land use *j*;
- UB_j = Upper bound of X_j;
- LB_j = Lower bound of X_j; and
- *TA* = Total area.

4.8 Constraints

The limits, which take values for the design variables, are known as constraints. There are two types of constraints. The first type, commonly used in the design problem, is an inequality constraint:

$$G_S(x)/G\sim_S(x) \leq 1 \,\Big|\, s = 1, 2\ldots k \tag{4.7}$$

where $G_S(x)$ *and* $G\tilde{}_S(x)$ are the calculated and limited values of constraints, and k is the number of inequality constraint functions.

In this research, constraints are as follows:

$$UB_j \geq \sum_j X_j \geq LB_j \tag{4.8}$$

$$\sum_i \sum_j S_{ij} X_j \leq \sum_j W_j(TA) \tag{4.9}$$

$$\sum_i \sum_j S'_{ij} X_j = \sum_j W'_j(TA) \tag{4.10}$$

$$\sum_j X_j = TA \tag{4.11}$$

As the model performs its iterations, it progressively reduces the number of vehicular trips while keeping the areas of the individual land uses within the variation bound (Equation 4.9) (Equations 4.8 and 4.10), maximizing person trips to maintain the economic viability of a development (Equation 4.11), and keeping the total area constant

(Equation 4.12). The GA plots two objective functions on the *x*- and *y*-axes; the points on the GA plot denote the most optimal points which satisfy the objective function for the given constraints and variables.

4.9 Standard Formulation

As previously mentioned, the final formulation of the optimization problem can be mathematically represented by:

$$min(F(\mathbf{x})) \tag{4.12}$$

subject to Equations 4.5, 4.6, and 4.7.

4.10 Optimization Tool

There are several computational tools in the literature which can be used for optimization such as Wolfram Mathematica, MATLAB, Microsoft Excel, C/C++ etc. For this research, MATLAB was selected as the most preferred software since it has a built-in optimization tool box and built-in algorithms like the GA which is convenient for analysis. This section presents an overview of the methodology adopted for obtaining optimized results.

4.11 Phase 1: Optimization with MATLAB Toolbox

The mathematical equations for various functions such as objective functions, constraints, and conditions are developed using the travel demand characteristics of various land uses using the spreadsheets. Once the function has been obtained, it can be written into the

MATLAB code. The derivation of the mathematical functions for person trip and vehicular trip is illustrated below.

4.12 Formulation of a Land Use Optimization Model

For the purpose of this research, travel behavior characteristics and vehicular and person trips are used to develop the model to optimize the mix of land uses and sizes to create less auto-dependent development compared to the initial area. However, this methodology can be applied to any time period or urban area where adequate travel demand characteristics are available. For the purpose of simplicity, travel demand characteristics are simplified in the manner described below.

A summary of the steps taken in this table is shown below:

Step 1: Establish a ratio of person trips *PT* per each land use:

$$W'_j = PT_j/X_j \tag{4.13}$$

Step 2: Establish a ratio of vehicle trips *VT* per each land use:

$$W_j = VT_j/X_j \tag{4.14}$$

Step 3: Establish a ratio of total person trips to total area of the mixed development:

$$W' = \sum_j PT_j / TA \tag{4.15}$$

Step 4: Establish the ratio between total vehicular trips Z to total area of the mixed development:

$$Z = \sum VT_j / TA \tag{4.16}$$

Step 5: Compute total person trips of a given land use to a total area of the mixed-use development:

$$\sum_j PT_j = \sum_j W'_j * X_j \tag{4.17}$$

Step 6: Compute total vehicle trips of a given land use to a total area of the mixed-use development:

$$\sum_j VT_j = \sum_j W_j * X_j \tag{4.18}$$

4.13 Variation Bounds

In order to develop an optimal size for each land use, it is essential to establish an upper and lower bounds of each land use that could be potentially allowed. Since the land development industry considers 5% to 50% as acceptable, the GA optimization was run for a total of 10 scenarios of differing variation bound (5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, and 50%). The optimization methodology will be applied using a "Perturbation-Iteration method or hill-climbing" approach while the size will be varied incrementally between -5% to +5% for each land uses. Each scenario will have multiple simulation runs. As each run progresses, the total number of automobiles generated by all land uses should decrease while maintaining the person trips same as in the initial area.

4.14 Implementation

The GA was implemented for single objective optimization with the given constraints and fitness function.

4.15 Looping for Better Performance

The initial population was set to the observed table values for each land use area. In the first run, the optimization terminated without much improvement in vehicle trip value, because the average change in the fitness value was less than the desired value as well as constraint violation. To overcome this early termination, the following procedure was implemented:

1. Run the GA optimization on infinite loop (Figure 4.1).
2. Start the loop with the initial population set to the values from the observed table.
3. For each loop, set the initial population to the optimized value of each variable obtained from the previous run. Now, the optimization starts with previously obtained results and therefore tries to optimize vehicle trip further.
4. Stop the loop when the vehicle trip does not change more than a small value, say delta (~= 0.2), over 5 iterations.

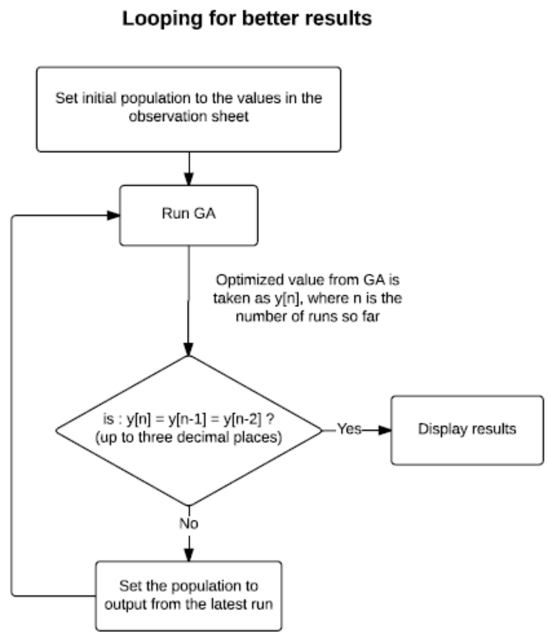


Figure 4.1 Flow chart showing the loop to optimize the land uses using the global optima.

In this way, the vehicle trip minimization is improved over each iteration and the final converged value is taken to be the final optimized value. This eliminates the chances of getting stuck or abandoned at local minima and population generation in case of tight constraints.

4.16 Description of the Willets Point Development

As explained in Chapter 3, the recently approved Willets Point Development is considered as a case study to assess and validate the land use optimization methodology developed in this research. This Chapter will discuss the travel demand characteristics of the Willets Point Development that was approved by the New York City Economic Development Corporation (NYCEDC) in 2013 after successfully going through an extensive environmental review (New York City Department of Environmental Protection, 2014). The approved development (the “initial area”) contains over 10 million square feet of mixed-use development and generates a significant amount of vehicular and person trips – 7,300 and 32,000 trips per hour, respectively, during the weekday PM peak hour.

The approved Willets Point Development will be built in three phases. Upon completion, the project will total approximately 10.3 million square feet (sf) of development, including up to 5.85 million sf of residential use (approximately 5,850 units); up to 1.25 million sf of retail; approximately 500,000 sf of office; up to 400,000 sf of convention center; up to 560,000 sf of hotel (approximately 700 rooms); approximately 150,000 sf of community facility; approximately 230,000 sf of public school; and a minimum of 8 acres of publicly-accessible open space. The projected number of proposed parking based on project-generated demand is approximately 6,700 spaces. Table 4.1 summarizes the land use by parcel, size, and overall size of the project.

4.16.1 Modal Split and Project Generated Trips

According to the Willets Point Development Final Supplemental Environmental Impact Statement (FSEIS) (NYCEDC, 2013), the travel demand estimates were prepared for nine land use types. Table 4.2 shows the travel demand forecast, which estimates the number of trips made by various land uses by mode and time of day. As discussed in Section 4.12, these factors have been unified for the purpose of the GA. The unified factors are shown in Table 4.3 and the model-specific equations are shown in Equations 4.19 and 4.20. It is important to note from this table that each land use has a different percentage of trips made by automobile, transit, rail, and non-motorized trips such as walking or biking including the link trip or internal capture.

Table 4.1 The Willets Point Development Initial Area

Use	Size
Willets West [1]	
Destination Retail	915,000 SF
Movie Theater	4,000 Seats
	(80,000 SF) [2]
Special Willets Point District	
Residential	5,850 DU
Destination Retail	657,000 SF
Local Retail	593,000 SF
Office	500,000 SF
Convention Center	400,000 SF
Hotel	700 Rooms
Community Facility	150,000 SF
Public School (K-8)	1,463 Seats
Lot B Development	
Destination Retail	184,500 SF
Office	280,000 SF
Total	
Residential	**5,850 DU**
Destination Retail	**1,756,500 SF**
Movie Theater	**4,000 Seats**
Local Retail	**593,000 SF**
Office	**780,000 SF**
Convention Center	**400,000 SF**
Hotel	**700 Rooms**
Community Facility	**150,000 SF**
Public School (K-8)	**1,463 Seats**

Notes:
(1) Willets West would contain approximately 1.4 million sf of development, including 400,000 sf of non-leasable common area. This ancillary space is not considered for trip generation purposes.
(2) *Willets Point Development Plan FGEIS* (2008) assumption of 20 sf per seat.
SF = square feet
DU = dwelling unit

Source: NYCEDC, "Willets Point Final Supplemental Environmental Impact Statement," 2013, Ch. 14, p. 14-46. https://www.nycedc.com/sites/default/files/filemanager/Projects/Willets_Point_Redevelopment/ Environmental_Review/FSEIS/07DME014Q_FEIS_14_Transportation.pdf. Accessed October 17, 2018.

Table 4.2 Travel Demand Factors of Various Land Uses

Land Use	Residential				Office				Destination Retail				Local Retail				Convention/Expo Facility				Movie Theater			
Person Trips																								
Daily Trip Rate	8.075 / DU (1)				18.0 / 1,000 SF (1)				78.2 / 1,000 SF (1)				205.0 / 1,000 SF (1)				46.2 / 1,000 SF (3)				3.26 / Seat (1)			
Linkage Trip Credit													(3) 25%											
Modal Split	(2)				(3, 4)				(3)				(3)				(3)				(3)			
	AM	MD	PM	EVE	AM	MD	PM	EVE	AM	MD	PM	EVE	AM	MD	PM	EVE	AM	MD	PM	EVE	AM	MD	PM	EVE
Auto	26.0%	26.0%	26.0%	26.0%	51.0%	25.5%	51.0%	51.0%	59.0%	59.0%	59.0%	59.0%	15.0%	15.0%	15.0%	15.0%	68.0%	68.0%	68.0%	68.0%	56.0%	56.0%	56.0%	56.0%
Taxi	1.0%	1.0%	1.0%	1.0%	1.0%	0.5%	1.0%	1.0%	3.0%	3.0%	3.0%	3.0%	0.0%	0.0%	0.0%	0.0%	8.0%	8.0%	8.0%	8.0%	7.0%	7.0%	7.0%	7.0%
Subway	52.0%	52.0%	52.0%	52.0%	16.0%	8.0%	16.0%	16.0%	15.0%	15.0%	15.0%	15.0%	5.0%	5.0%	5.0%	5.0%	12.0%	12.0%	12.0%	12.0%	18.0%	18.0%	18.0%	18.0%
Bus	10.0%	10.0%	10.0%	10.0%	14.0%	7.0%	14.0%	14.0%	18.0%	18.0%	18.0%	18.0%	10.0%	10.0%	10.0%	10.0%	2.0%	2.0%	2.0%	2.0%	8.0%	8.0%	8.0%	8.0%
Walk Only	11.0%	11.0%	11.0%	11.0%	18.0%	59.0%	18.0%	18.0%	5.0%	5.0%	5.0%	5.0%	70.0%	70.0%	70.0%	70.0%	10.0%	10.0%	10.0%	10.0%	11.0%	11.0%	11.0%	11.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Vehicle Occ.	(2)	(2)	(2)	(2)	(4)	(4)	(4)	(4)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)
	AM	MD	PM	EVE	AM	MD	PM	EVE	AM	MD	PM	EVE	AM	MD	PM	EVE	AM	MD	PM	EVE	AM	MD	PM	EVE
Auto	1.39	1.39	1.39	1.39	1.14	1.14	1.14	1.14	2.05	2.05	2.05	2.05	2.00	2.00	2.00	2.00	2.30	2.30	2.30	2.30	2.52	2.52	2.52	2.52
Taxi	1.39	1.39	1.39	1.39	1.14	1.14	1.14	1.14	2.05	2.05	2.05	2.05	2.00	2.00	2.00	2.00	1.80	1.80	1.80	1.80	2.30	2.30	2.30	2.30
Temporal Distrib.	(1)	(1)	(1)	(3)	(1)	(1)	(1)	(3)	(1)	(1)	(1)	(3)	(1)	(1)	(1)	(3)	(3)	(3)	(3)	(3)	(1)	(1)	(1)	(3)
	AM	MD	PM	EVE	AM	MD	PM	EVE	AM	MD	PM	EVE	AM	MD	PM	EVE	AM	MD	PM	EVE	AM	MD	PM	EVE
	10.0%	5.0%	11.0%	8.3%	12.0%	15.0%	14.0%	0.9%	3.0%	9.0%	9.0%	7.8%	3.0%	19.0%	10.0%	7.6%	5.5%	7.1%	12.7%	11.7%	1.0%	3.0%	8.0%	13.0%
Percent In/Out	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(1)	(1)	(1)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)
In	20.0%	51.0%	65.0%	70.0%	96.2%	48.0%	5.0%	20.0%	61.0%	55.0%	47.0%	50.0%	50.0%	50.0%	50.0%	50.0%	100.0%	73.0%	3.0%	1.0%	95.0%	62.0%	54.0%	53.0%
Out	80.0%	49.0%	35.0%	30.0%	3.8%	52.0%	95.0%	80.0%	39.0%	45.0%	53.0%	50.0%	50.0%	50.0%	50.0%	50.0%	0.0%	27.0%	97.0%	99.0%	5.0%	38.0%	46.0%	47.0%
Delivery Trips																								
Daily Trip Rate	0.06 / DU (1)				0.32 / 1,000 SF (1)				0.35 / 1,000 SF (1)				0.35 / 1,000 SF (1)				0.70 / 1,000 SF (3)				0.02 / Seat (3)			
Temporal Distrib.	(1)	(1)	(1)	(3)	(1)	(1)	(1)	(3)	(1)	(1)	(1)	(3)	(1)	(1)	(1)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)
	AM	MD	PM	EVE	AM	MD	PM	EVE	AM	MD	PM	EVE	AM	MD	PM	EVE	AM	MD	PM	EVE	AM	MD	PM	EVE
	12.0%	9.0%	2.0%	2.0%	10.0%	11.0%	2.0%	2.0%	8.0%	11.0%	2.0%	1.0%	8.0%	11.0%	2.0%	1.0%	7.9%	14.7%	1.1%	1.1%	12.0%	11.0%	1.0%	1.0%
Percent In/Out	(1)	(1)	(1)	(3)	(1)	(1)	(1)	(3)	(1)	(1)	(1)	(3)	(1)	(1)	(1)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)
In	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
Out	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%

Rates	Hotel				Community Facility				PS/IS - Students				PS/IS – Faculty				Recreational Uses			
Person Trips																				
Daily Trip Rate	9.4 / Room (1)				34.0 / 1,000 SF (3)				2.0 / Seat (3)				2.0 / Staff (3)				190.3 / Acre (5)			
Linkage Trip Credit																	(6) 25%			
Modal Split	(3)				(2,3)				(3)				(3)				(7)			
	AM	MD	PM	EVE	AM	MD	PM	EVE	AM	MD	PM	EVE	AM	MD	PM	EVE	AM	MD	PM	EVE
Auto	70.0%	70.0%	70.0%	70.0%	13.0%	13.0%	13.0%	13.0%	15.0%	15.0%	15.0%	15.0%	50.0%	50.0%	50.0%	50.0%	59.0%	59.0%	59.0%	59.0%
Taxi	15.0%	15.0%	15.0%	15.0%	0.5%	0.5%	0.5%	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.0%	3.0%	3.0%	3.0%
Subway	5.0%	5.0%	5.0%	5.0%	26.0%	26.0%	26.0%	26.0%	15.0%	15.0%	15.0%	15.0%	50.0%	50.0%	50.0%	50.0%	15.0%	15.0%	15.0%	15.0%
Bus	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	10.0%	10.0%	10.0%	10.0%	0.0%	0.0%	0.0%	0.0%	18.0%	18.0%	18.0%	18.0%
Walk Only	5.0%	5.0%	5.0%	5.0%	55.5%	55.5%	55.5%	55.5%	60.0%	60.0%	60.0%	60.0%	0.0%	0.0%	0.0%	0.0%	5.0%	5.0%	5.0%	5.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Vehicle Occ.	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(7)	(7)	(7)	(7)
	AM	MD	PM	EVE	AM	MD	PM	EVE	AM	MD	PM	EVE	AM	MD	PM	EVE	AM	MD	PM	EVE
Auto	1.60	1.60	1.60	1.60	1.50	1.50	1.50	1.50	1.30	1.30	1.30	1.30	1.20	1.20	1.20	1.20	2.05	2.05	2.05	2.05
Taxi	1.40	1.40	1.40	1.40	1.50	1.50	1.50	1.50	1.30	1.30	1.30	1.30	1.20	1.20	1.20	1.20	2.05	2.05	2.05	2.05
Temporal Distrib.	(1)	(1)	(1)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(5)	(5)	(5)	(8)
	AM	MD	PM	EVE	AM	MD	PM	EVE	AM	MD	PM	EVE	AM	MD	PM	EVE	AM	MD	PM	EVE
	8.0%	14.0%	13.0%	6.6%	7.2%	7.1%	8.3%	6.4%	45.0%	0.0%	7.5%	0.0%	45.0%	0.0%	5.0%	0.0%	3.2%	12.8%	12.8%	0.0%
Percent In/Out	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(9)	(9)	(9)	(8)
In	41.0%	68.0%	59.0%	60.0%	94.0%	45.0%	42.0%	50.0%	100.0%	0.0%	100.0%	0.0%	100.0%	0.0%	0.0%	0.0%	50.0%	57.0%	49.0%	50.0%
Out	59.0%	32.0%	41.0%	40.0%	6.0%	55.0%	58.0%	50.0%	100.0%	100.0%	100.0%	100.0%	0.0%	100.0%	100.0%	100.0%	50.0%	43.0%	51.0%	50.0%
Delivery Trips																				
Daily Trip Rate	0.24 / Room (3)				0.38 / 1,000 SF (3)				0.04 / Seat (3)				N/A N/A				3.48 / Acre (9)			
Temporal Distrib.	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(9)	(9)	(9)	(8)
	AM	MD	PM	EVE	AM	MD	PM	EVE	AM	MD	PM	EVE	AM	MD	PM	EVE	AM	MD	PM	EVE
	12.0%	9.0%	0.0%	0.0%	6.0%	11.0%	1.0%	0.0%	9.7%	7.8%	5.1%	0.0%	0.0%	0.0%	0.0%	0.0%	12.0%	9.0%	2.0%	0.0%
Percent In/Out	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(9)	(9)	(9)	(8)
In	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
Out	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%

Sources:
(1) New York City Mayor's Office of Environmental Coordination, *City Environmental Quality Review Technical Manual* (2012)
(2) U.S. Census Bureau 2006-2010 American Community Survey 5-Year Estimates. Journey to Work Data.
(3) *Willets Point Development Plan FGEIS* (2008)
(4) U.S. Department of Commerce, Bureau of the Census, *Census 2000*. Reverse Journey to Work Data.
(5) Institute of Transportation Engineers, *Trip Generation Manual, 8th Edition* (2008), Land Use 435 (Multipurpose Recreational Facility). Temporal distribution based on the ratio of peak hour of generator trip rates versus the total daily trip rates. Weekday midday temporal distribution assumed the same as weekday PM.
(6) Linkage accounts for synergy with recreational uses in adjacent Flushing Corona Meadows Park
(7) Assumed the same as the destination retail land use
(8) The recreational uses component would only be in use during non-game days and the off-season, it would not generate any trips during game day related peak hours.
(9) *Coney Island Rezoning FEIS* (2009) - Amusement Park Use. Delivery trip rate converted from per 1,000 square feet to per acre.

Table 4.3 Unified Travel Demand Factors Based on the Travel Demand Characteristics of Various Land Uses

	Residential	**Office**	**Destination**	**Retail**	**Convention**	**Cinema**	**Hotel**	**Community Facility**	**School**	**Total**
Area	5850.00	780.00	1757.00	593.00	400.00	80.00	560.00	150.00	230.00	10400.00
Person Trips	5054.55	1923.48	10394.11	9919.74	2346.96	1043.20	313.70	423.30	438.90	31857.90
Vehicle Trips	1263.64	877.38	3143.59	743.98	775.52	260.80	166.65	46.56	50.64	7328.75
PT/Area	0.86	2.47	5.92	16.73	5.87	13.04	0.56	2.82	1.91	3.06
VT/Area	0.22	1.12	1.79	1.25	1.94	3.26	0.30	0.31	0.22	0.70

$$0.864X_{res} + 2.466X_{off} + 5.9158X_{des} + 16.728X_{ret} + 5.8674X_{con} + 13.04X_{cin} + 0.56X_{hot} + 2.822X_{cf} + 1.9X_{sch} \geq 3.06326TA \quad (4.19)$$

$$0.216X_{res} + 1.125X_{off} + 1.789X_{des} + 1.255X_{ret} + 1.939X_{con} + 3.26X_{cin} + 0.298X_{hot} + 0.31X_{cf} + 0.22X_{sch} < 0.7047TA \quad (4.20)$$

where

- X_{res} = Residential area;
- X_{off} = Office area;
- X_{des} = Destination area;
- X_{ret} = Retail area;
- X_{con} = Convention Center area;
- X_{cin} = Cinema area;
- X_{hot} = Hotel area;
- X_{cf} = Community Facility area; and
- X_{sch} = School area.

The Willets Point Development generates substantial amount of person trips ranging from 18,000 to 39,000 in one single hour during the weekday AM, midday, PM, and Saturday midday (non-game day) peak hours. On game days, the fully built-out proposed project generates 30,000 person trips in one single hour during the weekday PM pre-game peak hour and in the range of 30,000 to 32,000 person trips in the Saturday pre-game and post-game peak hours. As a result, the vehicle trips would range from 4,500 to 8,800 vehicle in one single hour (automobile, taxi, and delivery) during the weekday AM, midday, PM, and Saturday midday (non-game day) peak hours. On game days, the project would generate approximately 7,000 vehicle trips in a single peak hour during the weekday PM pre-game peak hour and approximately 6,500 to 7,000 vehicle trips in the Saturday pre-game and post-game peak hours. The development's taxi trips have been adjusted based on the assumption that 25% of arriving taxis would depart with a fare in accordance with the guidelines set by the New York City Department of Transportation (NYCDOT). Due to the enormous amount of generated vehicle trips, this project impacts the street and highway networks and key intersections in the study area. As a result, many intersections and local roadway and highway networks experience significant delays, congestion, reductions in speed, and air quality impacts. Despite spending millions of dollars in mitigating such impacts, many of the impacted locations remain unmitigable. For this research, only the weekday PM peak hour was used but the methodology developed through this research can be applied to any time period and also to almost any urban area where adequate information on travel demand characteristics are available. In Tables 4.1 and 4.2, the land use optimization process is complicated by the existence of an exponentially large number of travel demand characteristics such as land use size, modal split, temporal distribution, automobile occupancy, and linked trip percentage.

The trip generation factors input used in the case study are obtained based on the 2014 *City Environmental Quality Review (CEQR)* Technical Manual stipulations, which include four different approved ways in which trip generation data can be obtained. In order of preference, these include: Census data (*American Community Survey (ACS);*

AASHTO Census Transportation Planning Products (CTPP)) for the area around the development site, data from previous environmental reviews/the 2014 *CEQR Technical Manual* itself, original surveys (which requires permission from NYCDOT; applying for this permission requires a technical memorandum which indicates how surveyors will comply with 2014 *CEQR Technical Manual criteria*), and the *Institute for Transportation Engineers (ITE) Trip Generation Manual*. If data for a desired land use is not available near the proposed site, the 2014 *CEQR Technical Manual* states that data should be obtained from neighborhoods with similar travel demand characteristics and neighborhood characteristics. This is the standard procedure that is used in travel demand forecasting across the country to avoid legal challenges. Most importantly, it cannot be emphasized enough that all data is scrutinized very thoroughly by NYCDOT before it is approved to be used in traffic analyses.

4.17 Initial Results

Initially, the GA was run for two different cases as follows.

In **Case 1**, the variation bound was set at 15%. The upper bound and lower bound values are tabulated in Table 4.4. The output of the GA is tabulated in Table 4.5 and is compared with the original values from the observed data in the table.

From Table 4.5, it can be observed that the person trips for Case 1 are approximately equal to the person trips for the initial area, and the vehicle trips have decreased by about 5.3%. As per the individual land uses, it was discovered that the convention center land use had the largest decrease in area (14.9%) and that the local retail area had the largest increase in area (15%).

Table 4.4 Lower and Upper Bounds for the 15% Variation Bound

Land Use	**Initial Area (ksf)**	**Lower Bound (15%)**	**Upper Bound (15%)**
Residential	5850	4972.5	9727.5
Office	780	663	897
Destination	1757	1493.45	2020.55
Retail	593	504	681.95
Convention Center	400	340	460
Cinema	80	68	92
Hotel	560	476	644
Community Facility	150	127.5	172.5
School	230	195.5	264.5

Table 4.5 GA Results for Case 1 (15% Variation Bound)

	Case 1 Results	Initial Area	Percent Change
Total Person Trips	31,860.12	31,857	0.01
Total Vehicle Trips	6,936.56	7,328.751	-5.35
Residential area (ksf)	6,083.69	5,850	3.99
Office Area (ksf)	763.50	780	-2.12
Destination Retail Area (ksf)	1,547.80	1,757	-11.91
Local Retail Area (ksf)	681.95	593	15.00
Convention Area (ksf)	340.41	400	-14.90
Cinema Area (ksf)	69.08	80	-13.64
Hotel Area (ksf)	476.56	560	-14.90
Community Facility (ksf)	172.50	150	15.00
School Area (ksf)	264.50	230	15.00
Total Area (ksf)	**10,400.00**	**10,400**	**0.00**

Table A.1 in Appendix A shows the results of each iteration of the GA under the constraints noted above. It was discovered that as the number of iterations increases, the total number of vehicle trips converges to a specific number.

In **Case 2,** the variation bound is set at 50%. The lower bound values are tabulated in Table 4.6 and the output of each genetic algorithm run is tabulated in Table A.2 in Appendix A and is compared with the original values from the observed data in the table.

From Table 4.6, it can be observed that the total vehicle trips have decreased by almost 18.7% while the total person trips have been kept close to the person trips in the initial area. It was discovered that increasing the variation bound proves to have a significant impact on vehicle trip reduction. Since the results were encouraging, eight additional cases were considered – 5%, 10%, 20%, 25%, 30%, 35%, 40%, and 45% variation bounds. These cases will be discussed in Chapter 5.

Table 4.6 GA Results for Case 2 (50% Variation Bound)

	GA results	Initial Area	Percent Change
Total Person Trips	31,860.11	31,857	0.010
Total Vehicle Trips	5,957.31	7,328.751	-18.713
Residential Area (ksf)	6,688.32	5,850	14.330
Office Area (ksf)	390.00	780	-50.000
Destination Area (ksf)	1,214.71	1,757	-30.865
Retail Area (ksf)	889.50	593	50.000
Convention Area (ksf)	200.00	400	-50.000
Cinema Area (ksf)	40.12	80	-49.845
Hotel Area (ksf)	479.97	560	-14.291
Community Facility (ksf)	152.38	150	1.585
School Area (ksf)	345.00	230	50.000
Total Area (ksf)	**10,400.00**	**10,400**	**0.00**

A common pattern that can be observed in the both Table 4.5 and Table 4.6 is that the reduction in destination area and increase in retail area has helped to improve the results. In Table 4.5, we observe that the convention area has been decreased by about 14.9% and the local retail area has been increased by about 15%. In Table 4.6, the convention area has been decreased by 50% and the retail area has been increased by 50%. Therefore, it was discovered that convention and local retail area can be concluded to have a major impact on decreasing vehicle trips.

Table A.2 in Appendix A shows the results of each iteration of the GA for Case 2 under the constraints noted above. It was discovered that as the number of iterations increases, the total number of vehicle trips converges to a specific number.

4.18 Code Breakup and Explanation

4.18.1 Task 1: Looping

The optimization searched the population based on a technique called "Perturbation-Iteration" which is commonly used in transportation. However, one of the hurdles that had to be overcome with the above methodology was the curtailment of the GA search as soon as it reaches the local optima. In order to continue the search through the population, in accord with the phenomenon of the global search, it was required to develop an algorithm as shown below.

```
      %% Loop over GA to find the most optimal solution

      % Initially initial population is set to table values (observed)
      % Every loop we update the initial population to newly found
optimal
      % solution. This helps us find a better solution, if there exists
any.
      clc;
      clear all;
      Result = [5850 780 1757 593 400 80 560 150 230];
      latest5Iterations = [0 0 0 0 0];
      ResultSet = [];

      while 1
        GARun;
        VT = vhballpara(Result);
        VT = floor(VT);

        latest5Iterations(1) = [];
        latest5Iterations = [latest5Iterations VT];
```

```
        if latest5Iterations(1) == latest5Iterations(2) ==
latest5Iterations(3) == latest5Iterations(4) == latest5Iterations(5)
          break
        end
      end
```

This code is to implement the looping part. Here the initial values of the variables from the table are set to a variable called Result. It is then used by GARun as initial population. The last five values of vehicle trip obtained from iterations is stored in variable called "latest5Iterations". The stopping condition for the infinite loop is if all five values of person latest5Iterations is the same.

4.18.2 Task 2: Fitness Function

```
      function [VT] = vhballpara(x)

      RA = x(1); %residential area range
      OA = x(2); %office area range
      DA = x(3); %destination area
      ReA = x(4); %retail area
      CA = x(5); %convention area
      CiA = x(6); %cinema area
      HA = x(7); %hotel area
      CfA = x(8); %community facility area
      SA = x(9) ; %school area

      VT =
(0.216*RA)+(1.12484*OA)+(1.7892*DA)+(1.2546*ReA)+(1.9388*CA)+(3.26*CiA)
+(0.2975*HA)+(0.3104*CfA)+(0.2202*SA); %vehicle trip
      end
```

This is the fitness function that calculates vehicle trips given the **x** vector.

4.18.3 Task 3: Calculating Coefficients and Constants

```
      %% Some constants

      CurrentArea = [5850 780 1757 593 400 80 560 150 230];
      CurrentTotalArea = sum(CurrentArea);

      % Obtained from table in full-scale mathematical model
```

```
	PT_per_Area = [0.864025 2.466 5.91583 16.728 5.8674 13.04
0.560175 2.822 1.90826087]; % Obtained from table in full-scale
mathematical model
	VT_per_Area = [0.21600625 1.124842105 1.789177854 1.2546
1.938793043 3.26 0.297592969 0.31042 0.220183946];

	TotalPT_currently = 31858;
	TotalVT_currently = 7329;

	TotalPT_perArea = TotalPT_currently/CurrentTotalArea;
	TotalVT_perArea = TotalVT_currently/CurrentTotalArea;

	%% Modeling variables/Parameters

	noVar = 9; % Number of variables
	TotalArea_desired = 10400;

	% UpperBound = +15% and LowerBound = -15%
	UB = CurrentArea *1.15;
	LB = CurrentArea *0.85;

	% Inequalities
	A = [-1 * PT_per_Area];
	B = [-1 * TotalPT_perArea * TotalArea_desired];

	% Equalities - TotalArea
	Aeq = [1 1 1 1 1 1 1 1 1];
	Beq = TotalArea_desired;

	% PT and VT
	PT_desired = TotalArea_desired *TotalPT_perArea;
	VT_desired = TotalArea_desired *TotalVT_perArea;

	% Fitness Function
	fitnessFunc = @vhballpara;
```

Constants are calculated which will be required for the current problem and these calculations follow the mathematical model derivation.

4.18.4 Task 4: Running the GA

```
	% GA Initial Population - options
	% Setting initial population to Result (previous run or initial
state)
	Population = Result;
	Score = vhballpara(Population);
	options =
gaoptimset('InitialPopulation',Population,'InitialScore',Score);
```

```
%% Running GA

[Areas, VehicTrip] =
ga(fitnessFunc,noVar,[],[],[],[],LB,UB,@constraints,options);
fprintf('Vehicle Trip: %.2f\n',VehicTrip);
Result = Areas; % Updating Results
```

The GA is run with the given inequality, equality constraints, and with the initial population set to appropriate values. The GA toolbox returns the optimized vehicle trip and the input variables for the optimized vehicle trip.

4.18.5 Task 5: Displaying Results

```
%% Displaying results

Result = [Result PT_per_Area*Result’ vhballpara(Result)];

fprintf('----------------------------------\n');
outputs =;
fprintf('Optimized results:\n\n');
fprintf('Total Vehicle Trip: %.2f\n',Result(11));
fprintf('Total Person Trip: %.2f\n\n',Result(10));

fprintf('Residential Area: %.4f\n',Result(1));
fprintf('Office Area: %.4f\n',Result(2));
fprintf('Destination Area: %.4f\n',Result(3));
fprintf('Retail Area: %.4f\n',Result(4));
fprintf('Convention Area: %.4f\n',Result(5));
fprintf('Cinema Area: %.4f\n',Result(6));
fprintf('Hotel Area: %.4f\n',Result(7));
fprintf('Community facility Area: %.4f\n',Result(8));
fprintf('School Area: %.4f\n\n',Result(9));

fprintf('Total Area: %.2f\n',sum(Result(1:9)));

fprintf('----------------------------------\n');
```

This is used to display the person trip, vehicle trip and all the individual areas.

Chapter 5 discusses the findings of the additional variation bounds and Chapter 6 examines additional land use attributes to examine the optimal mix of land uses and sizes, the findings of the results, and further interpretation and assessment of the above methodology based on the results. Finally, it will provide the conclusion of the methodology with the recommendation that it is suited for real world applications. Chapter 7 expands the GA to additional developments in New York City.

4.19 Linear Regression Methodology

Once the GA is run as described above and in Chapters 5-7, it will become necessary to reduce the data in order to provide equations that can be used in any situation regionally. The methodologies from these chapters will spit out an optimal mix of land uses and sizes and the corresponding number of vehicle trips. The final equations will involve vehicle trips as a function of neighborhood characteristics. It should be noted that although travel demand characteristics are related to neighborhood characteristics, travel demand characteristics are typically associated with individual land uses, whereas neighborhood characteristics are not. Because this research aims to find a way to generate the optimal mix of land uses and sizes for a particular development with no assumptions about what to build, it is imperative to use these neighborhood characteristics since they are not tied to a specific land use. The research proposes two sets of equations: one equation is the "unified model" which indicates how many total vehicle trips a development should generate, and the other set is a series of equations that determine the vehicle trips each prospective land use type should generate (the "land use set"). It should be noted that the second set of equations is used to estimate the percentage of vehicle trips that should be assigned to each use.

As noted above, the equations the regression model will spit out indicate the number of vehicle trips as a function of neighborhood characteristics. Neighborhood characteristics were chosen because they are the metrics that can be best adapted universally, and these neighborhood characteristics tend to affect travel characteristics. For this purpose, the neighborhood is defined as the census tracts which were used to determine travel demand characteristics for the development. The characteristics include the development area (DA, in square feet), the auto ownership rate (AO, in vehicles per household), the neighborhood area (NA, in square miles), the number of households in the neighborhood (H), the household density (HD, in households/square mile), the number of jobs in the neighborhood (J), the job density (JD, in jobs/square mile), and the total density (TD, in households + jobs/square mile). It should be noted that it was discovered that auto ownership rate correlates almost perfectly with household income, and therefore auto ownership was used as a substitute for income. The neighborhood characteristics were obtained from *ACS* and *AASHTO CTPP* data.

The method chosen for performing the linear regression is called stepwise regression. There are multiple types of stepwise regression and they work in a manner that optimize the independent variables (the neighborhood characteristics) and select the independent variable(s) that best correlate with the dependent variable (vehicle trips). Depending on the method, variables may be added or removed. It should be noted that stepwise regression is not guaranteed to find the "best" subset for each subset size, and the results produced by different methods may not agree with each other.

Forward stepwise regression is an iterative process which chooses the subset models forward by adding or removing one variable at a time to the previously chosen subset. In the case of the unified model, forward selection starts by choosing the independent variable that accounts for the largest variance in the dependent variable for the first iteration. This will be the variable having the highest simple correlation. At each successive iteration, the variable that causes the largest decrease in the residual sum of squares is added to the model. In the case of the land use set, selection starts by choosing the independent variable with the largest absolute value of a Pearson Correlation Coefficient (PCC) and therefore the highest coefficient of determination in each iteration. For both the unified model and the land use set, a variable that is shown to be insignificant is removed as an alternative; this eliminates multicollinearity (Minitab Blog Editor, 2013). Without a termination rule, forward selection continues until all variables are in the model. For this research, the termination rule is an increase in information criteria as discussed below.

The computer programs for stepwise regression generally include criteria for terminating the selection process. In forward selection, the common criterion is the ratio of the reduction in residual sum of squares caused by the next candidate variable to be considered the residual mean square from the model including that variable. This criterion can be expressed in terms of a critical "F-to-enter" or in terms of a critical "significance level to enter" (SLE), where F is the "F-test" of the partial sum of squares of the variable being considered. The forward selection terminates when no variable outside the model meets the criterion to enter. This "F-test," and the ones to follow, should be viewed only as stopping rules rather than as classical tests of significance. The use of the data to select the most favorable variables creates biases that invalidate these ratios as significance tests (Berk, 1978).

The evaluation tools used in the unified model are the Akaike information criterion (*AIC*) (Akaike, 1973) and the Bayesian information criterion (*BIC*) (Schwartz, 1978), each of which is designed to penalize models with larger numbers of parameters as follows:

$$AIC = L^2 - 2df \tag{4.22}$$

$$BIC = L^2 - 2df*\ln(n) \tag{4.23}$$

where n is the sample size, L is the log likelihood value (a measure of model fit), and df is the degree of freedom (the number of values that are free to vary). Thus, models with lower values of information criteria have a better fit for a given number of parameters and therefore the lowest value is used as the termination condition in the model. When the sample size is large, *BIC* is preferred fit and for small to medium-sized samples, including this research, the *AIC* statistic is most commonly used.

In the case of the land use set, the termination condition is set at a point where the coefficient of determination decreases or the statistical significance is shown to be greater than 0.05. The statistical significance is a probability that all assumptions are true given the null hypothesis.

Regression analysis is a mathematical measure of the average relationship between two or more variables in terms of the original units of the data. In a bivariate distribution, while plotting points, the scatter diagram will cluster around some curve called the "curve of regression." If this curve is a straight line, it is called the "line of regression" and there is said to be linear regression between the variables; otherwise, the regression is said to be curvilinear. The line of regression is the line which gives the best estimate to the variable for any specific value of the other variable and therefore it is called the line of best fit. This line is obtained using the principle of least squares. This equation is in the following form:

$$v = mx+b \tag{4.24}$$

where v is the number of optimized vehicle trips; x is a neighborhood characteristic, and m and b are coefficients that must be calibrated based on the neighborhood characteristics. It should be noted that there can be multiple x variables for each equation. In this case, there is a corresponding m for each x. The m coefficient represents the rate of change of its corresponding x variable and is obtained via the following equation:

$$m = r^*\sigma_v/\sigma_x \tag{4.25}$$

where r is the correlation between x and v, σ_v is the standard deviation of v and σ_x is the standard deviation of x.

The term b represents the intercept, or the value of v when all x values are 0.

There are four important statistical assumptions: normality (sampled from a normal distribution), homoscedasticity (all variables have the same variance), linearity (the data can be displayed in a straight line), and an absence of correlated error. Data points that do not meet these criteria are considered outliers. These outliers can be classified into four types: procedural error, an extraordinary event, extraordinary observations, or observations that fall within the ordinary range of each of the variables. Outliers can be detected using univariate, bivariate (scatterplot), and multivariate methods such as the Mahalanobis D2 distance measure. For this research, an observation having a *D2/df* value exceeding 2.5 (in small samples) was considered an outlier. In larger sample sizes, *D2/df* values exceeding 3 or 4 can be considered as outliers.

Outliers are accounted for by transforming the independent variables unless they are heteroscedastic, in which case the dependent variable may have to be transformed. Variables are transformed using functions such as logarithms. However, in the case of the neighborhood characteristics, the transformations may vary from region to region and should be performed by regional departments of transportation or planning agencies.

Chapter 8 performs linear regression analysis on the results obtained in Chapters 5-7 to obtain simple equations that can be used in real-world situations.

CHAPTER 5

ASSESSMENT OF THE METHODOLOGY

5.1 Introduction

In Chapter 4, the use of the GA to optimize the mix of land uses and sizes was discussed. The method was developed to reduce the number of vehicular trips by taking into account the surrounding neighborhood characteristics to minimize adverse impacts while maintaining a similar number of total person trips as in the initial area for the economic benefit of investors and development. Chapter 4 also discussed the Willets Point Development, which was used as a case study, in terms of its size, travel demand characteristics, and number of vehicle and pedestrian trips to assess the effectiveness of the methodology. The validity of the trip generation characters used in the Willets Point Development are explained in Section 4.16.1 (page 62). The methodology that was developed through this research demonstrates that, by optimizing the mix of land uses and sizes in conjunction with the travel demand characteristics of the surrounding neighborhood, engineers can effectively reduce the number of auto-dependent trips and increase the number of non-motorized person trips based on the bounds and variation scenarios that were performed. However, the methodology that was developed in the previous chapter was tested for only two variation bounds – 15% and 50%.

This chapter will further examine the methodology that was developed in Chapter 4 by optimizing the mix of land uses and sizes using additional variation bounds to further ascertain the validity of the model.

5.2 Overall Assessment of the Optimized Land Use and Size Model

The methodology that was developed in Chapter 4 to optimize the mix of land uses and sizes is very effective in reducing the overall vehicular trip generation and, as a result, significant environmental benefits result. These include reduction in vehicular delay, spillback, congestion, vehicle miles traveled (VMT) and vehicle hours traveled, improvements to air quality and traffic safety, as well as financial benefits to the developer. The travel demand estimates of the initial area prepared for each of the nine land use types show that it would generate 31,858 person trips and 7,329 vehicle trips during the Weekday PM peak hour. The methodology was based on the phenomenon of single-objective optimization by varying the mix of land uses and the size of each use using the GA for only two variation bounds: 15% and 50%.

However, in this Chapter, GA will be performed for initial variation bounds – 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, and 50%. These additional analyses will not only assist in further validating the methodology, but it will also assist in suggesting a prescribed methodology that is practical and ready to use by professionals, environmentalists, and developers to optimize the mix of land use and size to minimize the vehicular trips and subsequently reduce or eliminate environmental impact.

The selection of these bounds and variations was based on the industry's accepted practice as was stated in the National Association of Industrial and Office Properties (NAIOP). Each of these scenarios goes through numerous iterations of optimization for each mix of land uses and sizes within the variation bounds prescribed in addition to other parameters, constraints, and looping that were developed using the trip generation characteristics of each land use based on the surrounding built environment as described in the previous chapter. The analysis shows that as the model goes through each iteration, it progressively reduces the number of vehicular trips generated while maintaining the same amount of person trips and overall development size as the Base Case. Based on the output of the model, the following key observations were discovered:

1. As the model runs through its iterations, it progressively reduces the number of vehicular trips. After a certain number of iterations, the net reduction in trip generation plateaus. In other words, after an exhaustive search within the specified range of the variation bound, the convergence of optimized mix of land uses and sizes causes vehicle trips to be reduced. After this point, the reduction in trip generation will not be substantial since the optimization process reached its global optima.

2. The model shows that the vehicle trip generation reductions are greater as the variation bound increases. For example, the vehicle trip reduction for 15% and 50 % bounds and variation are 2% and 19%, respectively.

3. A weighted average of land use sizes with respect to vehicular trip generation of all variation bounds (5% thru 50%– a total of 10 scenarios) show that the vehicular trip generation of the weighted average reduction is nearest to the 25% variation bound.

4. The 50% variation bound had the highest reduction in the vehicular trips.

The details of the above findings are discussed below.

5.2.1 A Detailed Discussion of Optimization Model Results

Table 5.1 shows the area of each land use for the iteration of each variation bound, 5% to 50%, at which the vehicle trip generation no longer reduces significantly because the change in the mix of land uses and sizes has reached its optimum. Table 5.1 also shows the associated number of vehicle trips and person trips. The vehicle trip generation begins to plateau at the 23rd, 15th, 56th, 48th, 39th, 123rd, 99th, 63rd, 93rd, and 16th iterations for 50%, 45%, 40%, 35%, 30%, 25%, 20%, 15%, 10%, and 5% variation bounds respectively. Figure 5.1 shows the vehicle trips plateauing for each variation bound.

Table 5.1 Summary of Land Use Size and Total Vehicle and Person Trips at the Point of Convergence of Each Variation Bound

Run No	Residential (DUs)	Office (ksf)	Destination Retail (ksf)	Local Retail (ksf)	Convention Center/Expo Facility (ksf)	Cinema (seats)	Hotel (ksf)	Community Facility (ksf)	School (ksf)	Total Area	Person Trips/day	Vehicle trips (VPH)
Proposed	6688	390	1215	889	200	2006	480	152	345	10400	31,860	5957
Original	5850	780	1757	593	400	4000	560	150	230	10400	31,858	7334
Difference	838	-390	-542	296	-200	-1994	-80	2	115	0	2	-1377
50%	14%	-50%	-31%	50%	-50%	-50%	-14%	1%	50%	0%	0%	-19%
Proposed	6513	653	1241	835	220	2200	343	217	333	10400	31,860	6222
Original	5850	780	1757	593	400	4000	560	150	230	10400	31,858	7334
Difference	663	-127	-516	242	-180	-1800	-217	67	103	0	2	-1112
45%	11%	-16%	-29%	41%	-45%	-45%	-39%	45%	45%	0%	0%	-15%
Proposed	6220	468	1442	788	240	2400	661	210	322	10400	31,860	6394
Original	5850	780	1757	593	400	4000	560	150	230	10400	31,858	7334
Difference	370	-312	-315	195	-160	-1600	101	60	92	0	2	-940
40%	6%	-40%	-18%	33%	-40%	-40%	18%	40%	40%	0%	0%	-13%
Proposed	6229	507	1423	783	260	2600	634	202	310	10400	31,860	6436
Original	5850	780	1757	593	400	4000	560	150	230	10400	31,858	7334
Difference	379	-273	-334	190	-140	-1400	74	52	80	0	2	-898
35%	6%	-35%	-19%	32%	-35%	-35%	13%	-35%	35%	0%	0%	-12%
Proposed	6174	863	1310	771	280	2810	452	195	299	10400	31,860	6603
Original	5850	780	1757	593	400	4000	560	150	230	10400	31,858	7334
Difference	324	83	-447	178	-120	-1190	-108	45	69	0	2	-731
30%	6%	11%	-25%	30%	-30%	-30%	-19%	30%	30%	0%	0%	-10%
Proposed	6012	851	1389	741	300	3036	571	188	287	10400	31,860	6742
Original	5850	780	1757	593	400	4000	560	150	230	10400	31,858	7334
Difference	162	71	-368	148	-100	-964	11	38	57	0	2	-592
25%	3%	9%	-21%	25%	-25%	-24%	2%	25%	25%	0%	0%	-8%
Proposed	6020	725	1501	712	320	3211	602	180	276	10400	31,860	6820
Original	5850	780	1757	593	400	4000	560	150	230	10400	31,858	7334
Difference	170	-55	-256	119	-80	-789	42	30	46	0	2	-514
20%	3%	-7%	-15%	20%	-20%	-20%	8%	20%	20%	0%	0%	-7%
Proposed	6084	764	1548	682	340	3454	477	172	264	10400	31,860	6937
Original	5850	780	1757	593	400	80	560	150	230	10400	31,858	7334
Difference	234	-16	-209	89	-60	-600	-83	22	34	0	2	-397
15%	4%	-2%	-12%	15%	-15%	-14%	-15%	15%	15%	0%	0%	-5%
Proposed	6017	702	1640	652	360	3654	537	165	253	10400	31,860	7046
Original	5850	780	1757	593	400	4000	560	150	230	10400	31,858	7334
Difference	167	-78	-117	59	-40	-346	-23	15	23	0	2	-288
10%	3%	-10%	-7%	10%	-10%	-9%	-4%	10%	10%	0%	0%	-4%
Proposed	5951	741	1697	623	380	3850	533	157	241	10400	31,860	7184
Original	5850	780	1757	593	400	4000	560	150	230	10400	31,858	7334
Difference	101	-39	-60	30	-20	-150	-27	7	11	0	2	-150
5%	2%	-5%	-3%	5%	-5%	-4%	-5%	5%	5%	0%	0%	-2%

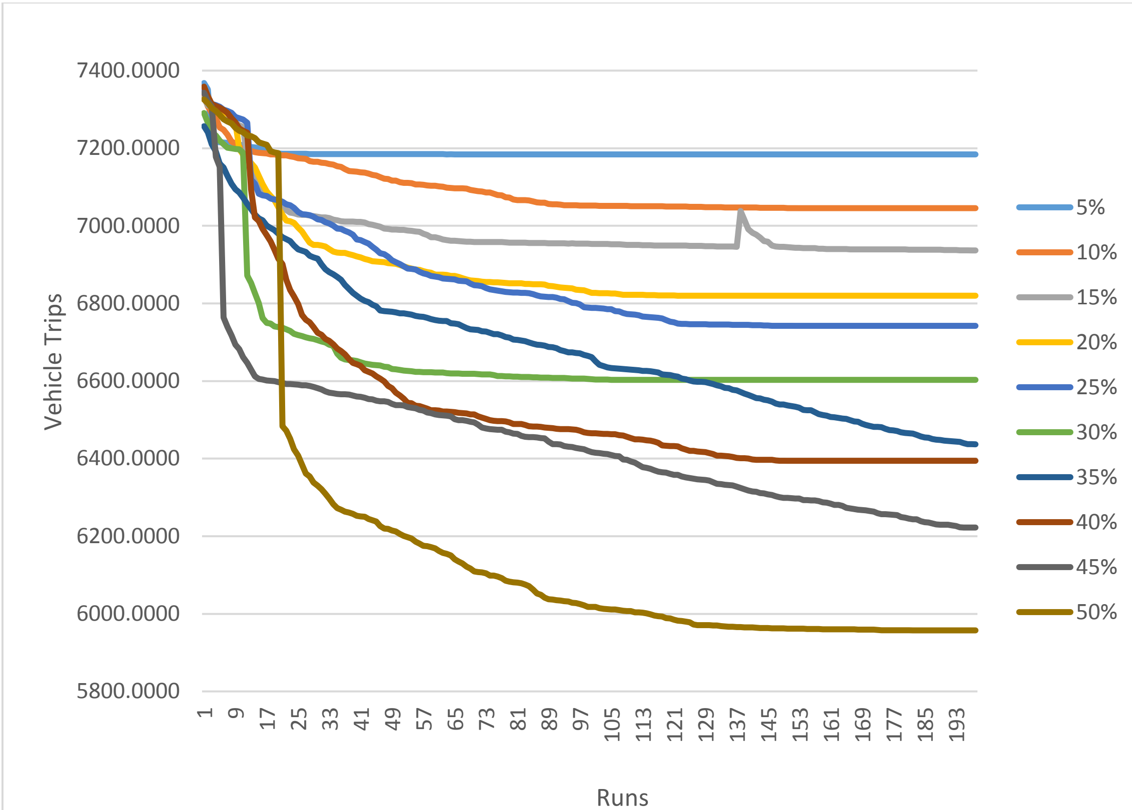


Figure 5.1 Auto trip generation of each iteration for each variation bound. Note that the vehicle trip generation plateaus after a certain iteration and that the vehicle trip reduction is higher with higher variation bounds.

As shown in Table 5.1, the 5% variation bound shows the lowest reduction in vehicular trips at 150 vehicles per hour (VPH) or a 2% reduction; the 10% variation bound shows 288 VPH or a 4% reduction; the 15% variation bound shows 397 VPH or a 5% reduction; the 20% variation bound shows 514 VPH or a 7% reduction; the 25% variation bound shows 592 VPH or an 8% reduction; the 30% variation bound shows 731 VPH or a 10% reduction; the 35% variation bound shows 898 VPH or a 12% reduction; the 40% variation bound shows 940 VPH or a 13% reduction; the 45% variation bound shows 1,112 VPH or a 15% reduction; and the 50% variation bound 1,377 VPH or a 19% reduction. Thus, the model clearly demonstrates that an optimization of the mix of land use and size within the variation bound would yield a substantial reduction in vehicular trip generation by maintaining the same person trips and total development area. Further examination of these results indicates that, as the variation bound increases, the reduction in vehicular trip generation steadily increases. However, after a certain point, the net reduction plateaus.

Table 5.2 indicates that the vehicular trip generation steadily decreases from the 5% variation bound to the 50% variation bound. In order to determine the "optimal" variation bound, the following steps were undertaken.

1. Identify the corresponding size of each land use, total vehicle trips, and total person trips at the point where the optimization plateaus for each bounds and variations scenarios (Figure 5.1 and Table 5.1 show the corresponding land use and its size and total auto and person trip generation at the point where optimization plateaus).

2. From the values above, calculate the weighted average of the area of each land use with respect to vehicle trips (Table 5.3).

3. Calculate the total vehicle and person trip generation for the weighted average of the land uses and sizes calculated above based on the similar travel demand characteristics as the in the initial area (Table 5.4).

4. Compare the above total vehicular and person trip generation of the weighted average with the total vehicular and person trip of each variation bound shown in Table 5.1 to identify the optimal variation bound and the corresponding mix of land uses and sizes.

Table 5.2 Percent Trip Reduction Under Each Variation Bound

Variation Bound	Vehicle Trip Generation Reduction
5%	-2%
10%	-4%
15%	-5%
20%	-7%
25%	-8%
30%	-10%
35%	-12%
40%	-13%
45%	-15%
50%	-19%

Table 5.3 Weighted Average of Land Use Area by Vehicle Trips

Land Use	Initial Area		50%		45%		40%		35%		30%		25%		20%		15%		10%		5%		Avg. Size
	Size	Veh. Trips	Size	Veh. Trips	Size	Veh. Trips	Size	Veh. Trips	Size	Veh. Trips	Size	Veh. Trips	Size	Veh. Trips	Size	Veh. Trips	Size	Veh. Trips	Size	Veh. Trips	Size	Veh. Trips	
Resi.	5,850	1,263	6,688	1,443	6,513	1,410	6,220	1,342	6,229	1,348	6,174	1,334	6,012	1,300	6,020	1,301	6,084	1,313	6,017	1,299	5,951	1,281	6,199
Office	780	877	390	432	653	723	468	518	507	562	863	958	851	944	725	808	764	854	702	784	741	840	702
Dest. Retail	1,757	3,143	1,215	2,175	1,241	2,220	1,442	2,580	1,423	2,547	1,310	2,348	1,389	2,484	1,501	2,686	1,548	2,770	1,640	2,935	1,697	3,033	1,457
Local Retail	593	744	889	1,116	835	1,048	788	988	783	982	771	968	741	927	712	892	682	856	652	820	623	780	756
Conv. Center	400	776	200	387	220	427	240	466	260	502	280	543	300	584	320	621	340	659	360	697	380	736	301
Movie Theater	4,000	261	2,006	130	2,200	146	2,400	156	2,600	170	2,810	183	3,036	204	3,211	209	3,454	228	3,654	239	3,850	249	3,042
Hotel	560	167	480	143	343	100	661	197	634	187	452	136	571	169	602	179	477	141	537	159	533	158	544
Comm. Facility	150	47	152	47	217	67	210	68	202	62	195	60	187	60	180	56	172	52	165	51	157	48	186
School	230	56	345	84	333	81	322	79	310	76	299	73	287	70	276	68	264	64	253	62	241	59	297

Table 5.4 Willets Point Development Optimized Vehicle Trips

	Initial Area		**Office**		**Destination Retail**		**Local Retail**		**Convention Center**		**Movie Theater**		**Hotel**		**Community Facility**		**School Students**		**School Staff**		**Total**
	Size	**Output**	**Size**	**Output**	**Size**	**Output**	**Size**	**Output**	**Size**	**Output**	**Size**	**Output**	**Size**	**Output**	**Size**	**Output**	**Size**	**Output**	**Size**	**Output**	
Size	6,199	N/A	702	N/A	1,457	N/A	756	N/A	301	N/A	3,042	N/A	544	N/A	186	N/A	1,889	N/A	164	N/A	N/A
Trip Rate	8.08		18.00		66.47		174.25		46.20		3.26		7.28		34.00		2.00		2.00		
Daily Person Trips	N/A	50,058	N/A	12,636	N/A	96,848	N/A	131,734	N/A	13,908	N/A	9,918	N/A	3,958	N/A	6,324	N/A	3,778	N/A	328	329,490
Peak Hour Temporal Distribution	10.7%	N/A	13.7%	N/A	8.9%	N/A	9.6%	N/A	12.7%	N/A	8.0%	N/A	7.7%	N/A	8.3%	N/A	15.0%	N/A	5.0%	N/A	
Peak Hour Person Trips	N/A	5,356	N/A	1,731	N/A	8,619	N/A	12,646	N/A	1,766	N/A	793	N/A	305	N/A	525	N/A	567	N/A	16	32,324
Peak Hour Person Trips in Vehicles	0.33	1,767	0.52	900	0.62	5,344	0.15	1,897	0.76	1,342	0.63	500	0.85	259	0.17	87	0.15	85	0.50	8	12,189
Peak Hour Veh. Trips	1.32	1,339	1.14	789	2.05	2,607	2.00	949	2.30	583	2.52	198	1.60	162	1.50	58	1.30	65	1.20	7	6,757

5.2.2 Calculation of the "Optimal" Mix of Land Uses and Sizes

Through the examination of the results of each variation bound scenario (Tables 5.5 through 5.14), it was found that after certain iterations, the travel demand converges and both the land use mix and vehicle trips plateau. Beyond this point (the "critical point"), no noticeable reductions in the vehicle trip generation occurs. The results of each scenario were plotted to better understand the plateau. Figure 5.1 is a plot of total vehicular trip generation of all the land uses of every iteration of optimization. As shown in Figure 5.1, the total vehicle trip generation plateaus at 23rd, 15th, 56th, 48th, 39th, 123rd, 99th, 63rd, 93rd, and 16th iterations for 50%, 45%, 40%, 35%, 30%, 25%, 20%, 15%, 10%, and 5% variation bounds, respectively. The corresponding values of each land use size and vehicle trips at the critical points are shown in Table 5.3. Based on these results, the weighted average of land use area with respect to weekday PM peak hour vehicle trip generation for each land use was calculated (last column of Table 5.3). Using the weighted average for each land use, the corresponding trip generation and person and vehicle trips for all the land uses were re-computed based on the same travel demand characteristics as shown in Table 5.4. According to the results shown in Table 5.4, the total auto trip generation, based on the weighted average of the land use and size, is 6,936 VPH. Comparison of this trip generation with the optimal trip generation of each variation bound, shown in Table 5.1, demonstrates comparable results between the weighted trip generation and the 25% variation bound as shown in Table 5.1. This research suggests two important discoveries:

1. Optimization of the mix of land uses and sizes will reduce the number of vehicular trips while keeping the person trips total development area at similar values to the initial condition – a win-win situation from the principles of smart development and financial benefits.

2. The 25% variation bound would yield the optimal mix of land uses and sizes that would achieve significant reduction in vehicular trips.

Table 5.4 shows that the optimal mix of land uses and sizes yields fewer vehicular trips (9% or 700 VPH) compared to the initial area. Although it is beyond the scope of this research, it should be mentioned that this reduction in vehicle trips is a huge monetary benefit to the developer due to savings in parking space construction, stormwater management, and both capital and maintenance costs and improves community safety.

Although this research demonstrates that this optimized land use methodology reduces the auto trip generation significantly, Chapter 6 further evaluates these results in conjunction with other land use attributes such as parking and Entropy Index.

CHAPTER 6

IMPLICATIONS OF OPTIMIZING THE MIX OF LAND USES AND SIZES

6.1 Introduction

The previous chapter developed a model based on the travel demand characteristics of the surrounding neighborhood using the GA in order to develop an optimal mix of land uses and sizes to minimize vehicle trips in a mixed-use development. The aim of the research is to develop a methodology that is practical and easily understandable the stakeholders to develop a range of ideal land use programs for a sustainable mixed-use development. The results showed that this methodology successfully yielded a range of ideal land uses and sizes for a particular area that generated same number of person trips as the initial area (for the financial success of the project) but minimized the number of vehicular trips compared to the initial area. This is a major step towards the reduction of adverse impacts such as traffic congestion, air quality and noise impacts, safety, and greenhouse gas emissions. This chapter assesses the findings of the methodology that is developed in the previous chapter and augments the methodology by further examining associated attributes of land use developments such as parking needs through its accumulation characteristics and the Entropy Index (EI) to assess the quality of the proportion of compatible land uses.

The following key areas were investigated in formulating a methodology:

- The land use model is developed in the previous chapters with variation bounds of 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, and 50% in the mix of land use and size relative to the initial area. As a result, under each variation bound, a range of ideal land uses and sizes were developed that generates the same number of person trips as the initial area while reducing the number of vehicle trips compared to the initial area.

- A parking accumulation methodology is developed for each variation bound to assess the parking demand to ensure that enough parking spaces are provided for each variation bound to meet peak parking demand during the daytime for workers, tenants, shoppers, and residents as well as peak demand during overnight for residents.
- An EI that assesses the proportion of the mix of compatible land uses is determined for the initial area and for each variation bound to determine if the optimal land use mix has a robust mix of uses.
- Both parking accumulation and the EI will be used in order to validate the results in Chapter 5.

6.2 Diagnostic Assessment of the GA Analysis on Land Use Mix

The GA analysis has been summarized in the previous chapters based on the travel demand characteristics to select the optimal mix of land uses and sizes for a sustainable development. The GA that was developed in the previous chapter used a perturbation-iteration method by altering the size of one land use and replacing the lost area with area added to a different land use that would generate the same number of person trips as the initial area and have the same total development area as in the initial area. If the number of vehicle trips stayed the same or rose, the GA rejected the iteration. If the number of vehicle trips fell, the GA accepted the iteration and the model ran again many times until the number of vehicle trips began to approach a critical point. As shown in Figure 5.1, in the previous chapter, the reduction in the number of vehicle trips plateaus at the critical point. The percent change of each land use for each variation bound at the critical point relative to the initial area is shown in Figure 6.1 and Table 6.1.

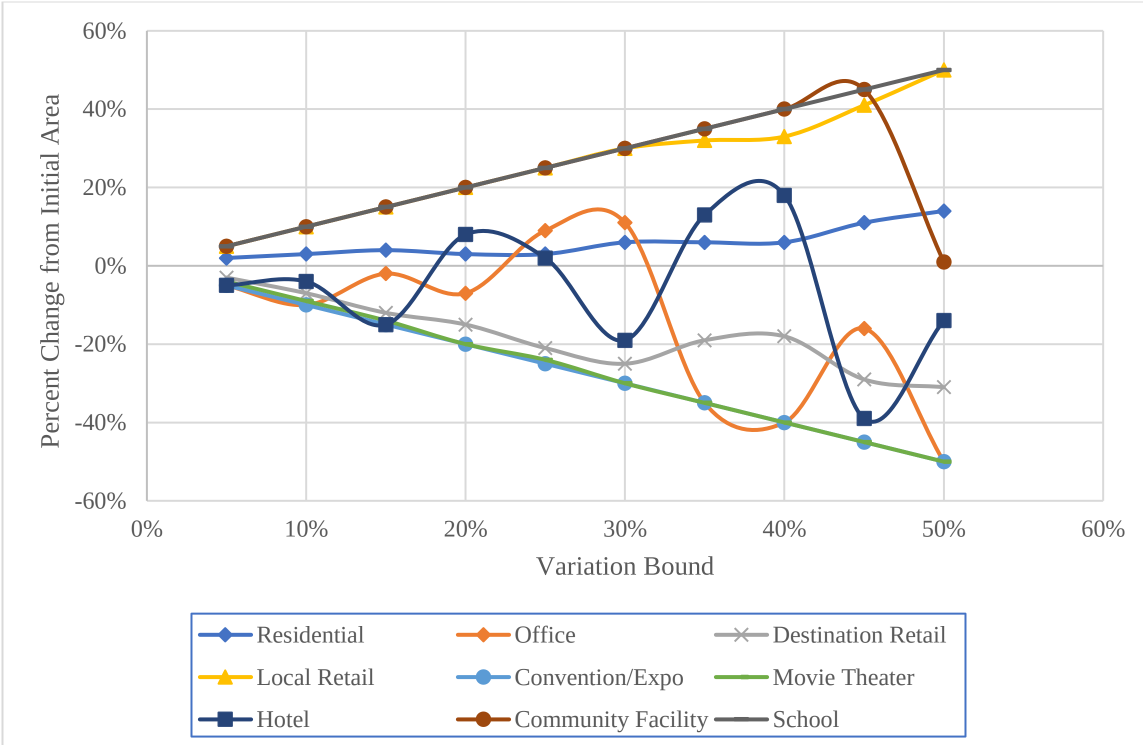


Figure 6.1 Change in land use as a function of variation bound for the Willets Point Development.

A detailed examination of Chart 6.1 discovered useful information from this research about optimizing the mix of land uses and sizes.

- The movie theater and convention/expo facility uses (land uses with a high percent auto mode share) dropped in size linearly from one program to another within 10% of the variation bound and are replaced with school, community facility, and local retail uses (land uses with a low auto mode share), which rise linearly in its sizes within 10% of the variation bound (with community facility and school uses rising the variation bound). Not only does this reduce the number of automobile trips, but it also has the increased amenities beneficial to a healthy neighborhood.

- In addition, the destination retail area decreases linearly within 15% of the variation bound if it is less than 30%. However, for variation bounds greater than 30%, the destination retail has a slight increase before decreasing at a lower rate This explains the fact that for large retail developments (such as malls), more of the trips will either be internal trips to multiple stores or linked trips between the retail and another use on-site.

Table 6.1 Change in Land Use as a Function of Variation Bound for the Willets Point Development

Variation Bound	Residential	Office	Destination Retail	Local Retail	Convention/Expo	Movie Theater	Hotel	Community Facility	School
Initial Area	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
5%	2%	-5%	-3%	5%	-5%	-4%	-5%	5%	5%
10%	3%	-10%	-7%	10%	-10%	-9%	-4%	10%	10%
15%	4%	-2%	-12%	15%	-15%	-14%	-15%	15%	15%
20%	3%	-7%	-15%	20%	-20%	-20%	8%	20%	20%
25%	3%	9%	-21%	25%	-25%	-24%	2%	25%	25%
30%	6%	11%	-25%	30%	-30%	-30%	-19%	30%	30%
35%	6%	-35%	-19%	32%	-35%	-35%	13%	35%	35%
40%	6%	-40%	-18%	33%	-40%	-40%	18%	40%	40%
45%	11%	-16%	-29%	41%	-45%	-45%	-39%	45%	45%
50%	14%	-50%	-31%	50%	-50%	-50%	-14%	1%	50%

- The change in residential units is more difficult to predict since its mode choice is dependent on neighborhood character, as census journey-to-work data from nearby census tracts is typically used to determine mode choice. In mid- to high-density urban environments such as New York, the residential use auto mode share tends to be lower than destination retail and entertainment uses but higher than local retail and community uses. Therefore, the residential use is likely to rise though not as significantly as local retail and community-based uses.

- Hotel and office uses fluctuate trigonometrically and therefore cannot be predicted by a linear or even an exponential or logarithmic model possibly due to the time-of-day variance in their mode choices.

These discoveries are important for the next steps of the research. Because every development has different land uses, and discrete land uses with similar mode shares will have different daily and hourly trip rates, it is important to categorize land uses into land use "types" that can be adaptable to any development. These land use types will be as follows:

1. The residential land use has travel demand characteristics that are sufficiently unique to give it its own land use type, "residential."

2. The office land use has travel demand characteristics that are sufficiently unique to give it its own land use type, "office." It should be noted that some developments contain industrial uses; these will be categorized as "office" as well.

3. Community-based land uses such as local retail, community facility, school, health club, small studio spaces, and others have similar mode choice characteristics and therefore can be categorized together as a "neighborhood" land use type.

4. Large destination land uses such as destination retail, movie theaters, medium- to large-sized event spaces, tourist attractions, large studios and others have similar mode choice characteristics and therefore can be characterized together as a "destination" land use type. For purposes of this analysis, the hotel use will be characterized as a destination-type land use because it is an uncommon use.

5. Supermarkets can be either folded into the neighborhood or a destination land use type depending on their functionality. Large or specialty markets can typically be counted as destination, whereas small supermarkets created in order to serve food deserts can be counted as neighborhood.

This research validates that, in a typical mid- to high-density urban environment with ample transportation options and complete streets, it is beneficial to select a range of land use mixes based on the travel demand characteristics of the surrounding neighborhood in order to reduce the auto-dependent land use area. This measure will reduce congestion and improve safety, neighborhood character, and the environment. Mixed-use developments also have the opportunity to balance traditionally auto-dependent land uses such as entertainment and destination retail with less auto-dependent uses such as local retail and community facilities. Not only does this provide a sustainable development, it also assists in meeting smart growth development goals.

6.3 Assessment of Parking Needs as a Determination of Best Land Use Mix

In order to develop a methodology for the parking accumulation, the number of vehicular trips per day must first be determined. For each land use, its size is multiplied by its daily person trip rate, its auto share percentage, and its vehicle occupancy of persons per auto. The formula for total daily vehicular trips is shown below:

$$A = sra/o \tag{6.1}$$

where A is the total number of daily vehicular trips, s is the size of the land use (in square feet, dwelling units, rooms, seats, etc.), r is the daily trip generation rate per unit size, a is the percent of person trips arriving or departing by auto, and o is the auto occupancy. The daily trip generation rate, auto mode share, and auto occupancy are determined from original surveys, surveys performed for recent studies and environmental reviews, and/or standard rates recommended by local agencies.

The number of daily trips for each land use is multiplied by an hourly temporal distribution for each land use to obtain the trip arrival and departure patterns; it is assumed that trips would be split 50-50 between arrivals and departures over the course of 24 hours and hourly patterns are based on a combination of original surveys, surveys performed for recent studies and environmental reviews, and/or standard rates recommended by local agencies.

Peak parking accumulation needs to be calculated in order to design the parking spaces to accommodate the peak demand. In order to determine the peak parking accumulation, demand at one hour must be set so that the parking accumulation can be based around that hour; accumulations for earlier hours add departing trips and subtract arriving trips, and accumulations for later hours add arriving trips and subtract departing trips. This hour is usually chosen to occur overnight, where there is minimal vehicular activity. Typically, residential overnight accumulation is based off of census data for Vehicles Available, and hotel overnight accumulation is based off of auto mode share and vehicle occupancy. Other uses will typically contribute zero vehicles or a handful of overnight employees (security, delivery) that can be assumed based on local survey data

The GA can be used to lower the number of parking spaces required to accommodate all parking demand. Table 6.2 and Figure 6.2 shows the 24-hour accumulation of the GA for each variation bound. As shown in Table 6.2 and Figure 6.2, the larger variation bounds have lower peak demands than the initial area. This is because, as mentioned above, high auto demand uses such as destination retail, convention, and movie theater uses are converted into lower auto demand uses such as residential, local retail, and community facility uses. However, because of the increase in residential use, overnight demand increases (see Table 6.2). For most land uses, the peak demand occurs in the midday and demand is almost zero overnight. For the residential and hotel uses, however, demand peaks overnight and vehicles leave during the day and return in the evening. Nevertheless, because the residential use is a low auto demand use in mid- to high-density urban environments, the demand still tends to peak in the midday and as the bounds and variances increase, the peak demand remains lower than in the initial area. As a result, demand tends to become flatter with less variation throughout the day as variation bounds increase, as shown in Figure 6.2.

Figure 6.3 shows the peak and overnight demands for each of the variation bounds. As shown in Figure 6.3 and as described above, in mid- to high-density urban environments, it was discovered that the overnight demand increases and the peak demand decreases as the variation bounds increase.

Because the overnight demand increases while the peak demand decreases, the two curves may intersect if the Vehicles Available percentage is high enough. The variation bound associated with this demand would be the optimal mix if the main objective were to reduce parking requirements. If, however, the two curves do not intersect, the variation bound with the lowest peak midday parking demand would be the optimized mix of land uses and sizes for parking.

Table 6.2 Parking Accumulations of Each Variation Bound

Hour Begins At	Variation Bound										
	Initial Area	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
12:00 AM	3,362	3,403	3,439	3,448	3,467	3,448	3,481	3,589	3,596	3,611	3,763
1:00 AM	3,355	3,395	3,432	3,441	3,463	3,445	3,477	3,588	3,596	3,607	3,762
2:00 AM	3,355	3,395	3,432	3,441	3,463	3,445	3,477	3,588	3,596	3,607	3,762
3:00 AM	3,355	3,395	3,432	3,441	3,463	3,445	3,477	3,588	3,596	3,607	3,762
4:00 AM	3,355	3,395	3,432	3,441	3,463	3,445	3,477	3,588	3,596	3,607	3,762
5:00 AM	3,355	3,395	3,432	3,441	3,463	3,445	3,477	3,588	3,596	3,607	3,762
6:00 AM	3,386	3,424	3,459	3,467	3,487	3,468	3,498	3,608	3,614	3,624	3,777
7:00 AM	3,353	3,374	3,393	3,393	3,405	3,387	3,401	3,470	3,463	3,463	3,567
8:00 AM	4,007	3,959	3,913	3,939	3,897	3,968	3,956	3,682	3,629	3,739	3,540
9:00 AM	5,145	5,019	4,893	4,905	4,787	4,885	4,830	4,285	4,169	4,325	3,880
10:00 AM	5,717	5,554	5,392	5,364	5,216	5,279	5,183	4,624	4,490	4,579	4,092
11:00 AM	6,091	5,903	5,721	5,653	5,488	5,502	5,370	4,856	4,714	4,727	4,253
12:00 PM	6,729	6,516	6,316	6,204	6,045	6,018	5,839	5,376	5,233	5,133	4,677
1:00 PM	6,831	6,611	6,404	6,300	6,133	6,117	5,937	5,433	5,285	5,202	4,710
2:00 PM	6,574	6,361	6,162	6,076	5,909	5,920	5,753	5,216	5,062	5,026	4,523
3:00 PM	6,400	6,195	5,997	5,911	5,743	5,747	5,589	5,074	4,932	4,896	4,406
4:00 PM	5,625	5,465	5,306	5,219	5,067	5,033	4,930	4,565	4,449	4,411	4,052
5:00 PM	4,335	4,279	4,208	4,104	4,033	3,923	3,835	3,867	3,823	3,661	3,621
6:00 PM	3,722	3,704	3,681	3,628	3,586	3,504	3,475	3,566	3,560	3,477	3,513
7:00 PM	4,104	4,086	4,071	4,017	3,979	3,891	3,866	3,985	3,983	3,896	3,963
8:00 PM	4,016	4,011	4,004	3,964	3,936	3,861	3,848	3,968	3,967	3,903	3,994
9:00 PM	3,286	3,317	3,339	3,343	3,345	3,319	3,347	3,431	3,426	3,448	3,572
10:00 PM	3,345	3,381	3,408	3,414	3,424	3,402	3,431	3,527	3,528	3,545	3,684
11:00 PM	3,371	3,412	3,447	3,455	3,472	3,453	3,486	3,592	3,597	3,615	3,764
Max Demand	6,831	6,611	6,404	6,300	6,133	6,117	5,937	5,433	5,285	5,202	4,710

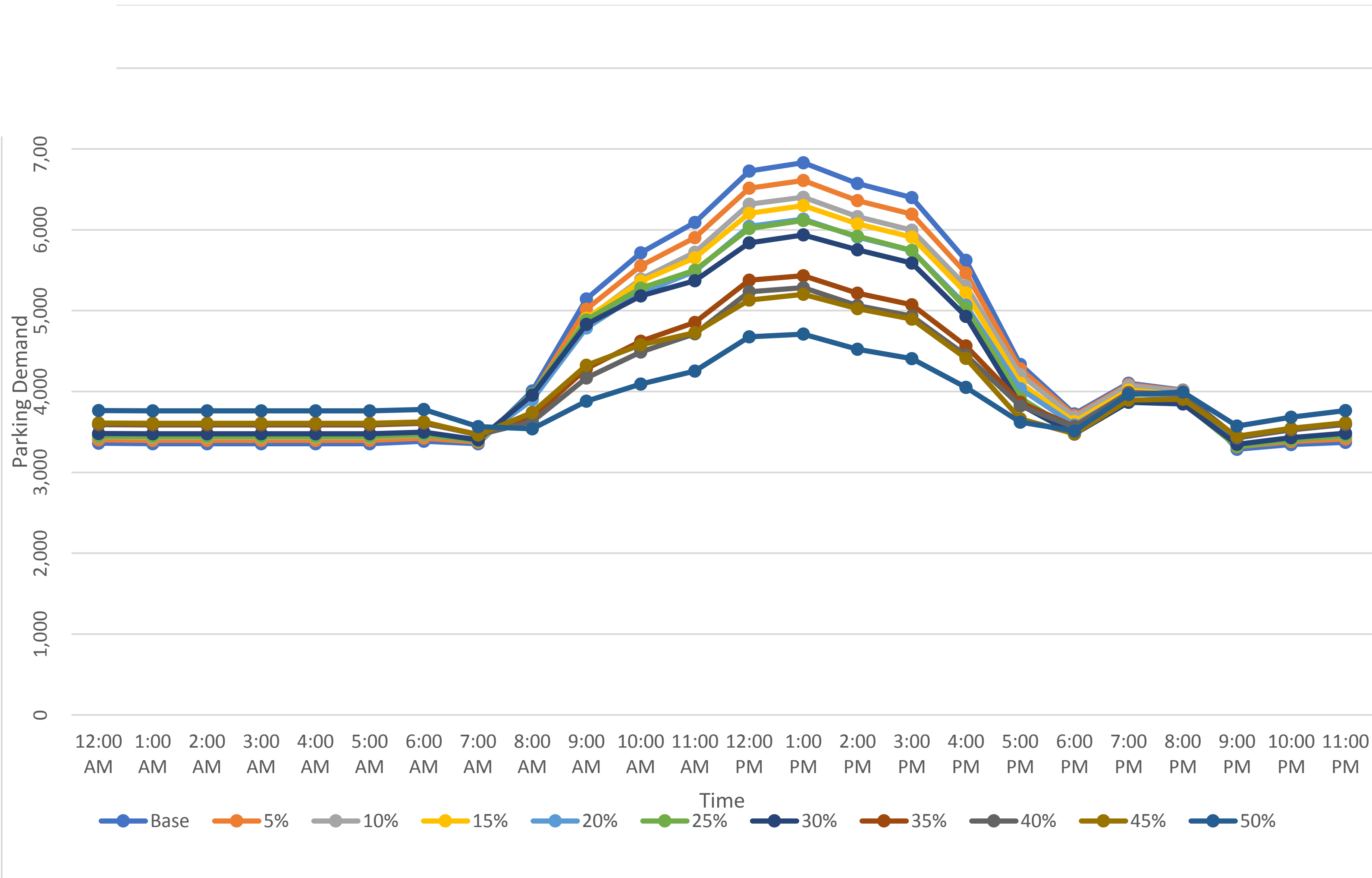


Figure 6.2 24-Hour parking demand for each variation bound. Note the peak demand always occurs in the midday.

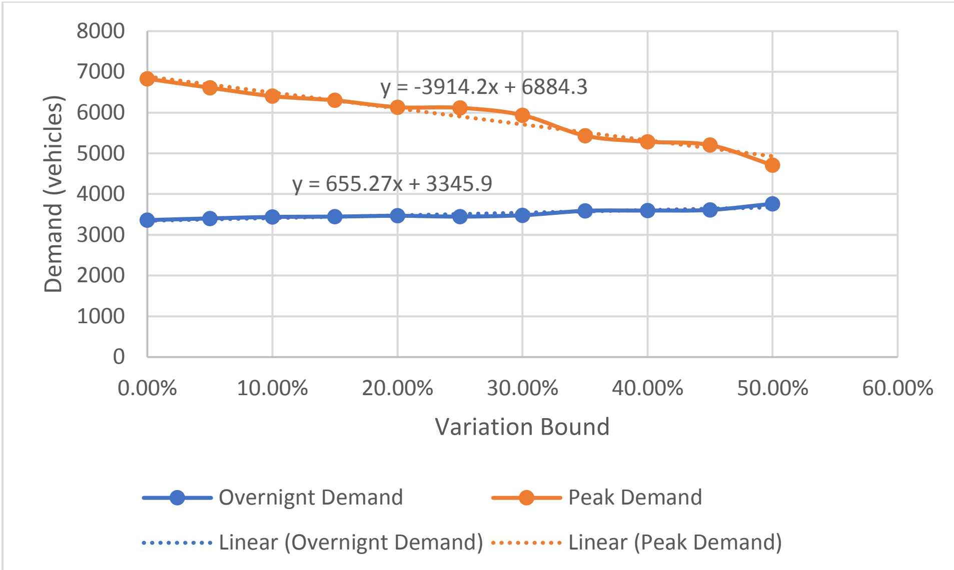


Figure 6.3 Overnight and peak parking demand for each variation bound. Note the peak demand decreases and the overnight demand increases with each variation bound.

6.4 Entropy Index

For a mixed-use community, it is desirable to have a diverse variety of land uses which have enough space to serve all of their associated residents and/or workers. The Entropy Index (EI) is a measure of the mix of land uses for a development, and it is determined by the following equation:

$$E = \frac{\sum_{i=1}^{n} p_i * ln(p_i)}{-ln(n)} \tag{6.2}$$

where n is the number of land uses, p is the percentage of land use i, and E is the Entropy Index. The Entropy Index is a value between 0 and 1, where 0 represents a case where only one land use is developed, and 1 represents the case where all land uses have an equal proportion. Table 6.3 shows the land proportion of each land use for each variation bound identified in Table 6.1 and Figure 6.1. As shown in Table 6.3, EI increases with the variation bound up to roughly 25% and then begins to decrease. This discovery validates the results in Chapter 5 that the optimized mix of land uses and sizes roughly corresponds to the 25% variation bound.

6.5 Summary

As shown above, optimizing the mix of land uses and sizes leads to some interesting discoveries. These discoveries include the ability to group land uses together into four land use types: residential, office, neighborhood, and destination. It was also discovered that land use optimization can reduce the parking requirements of a development and the optimal mix of land uses and sizes from Chapter 5 corresponds roughly to the optimal Entropy Index. Chapter 7 will apply the methodology developed in Chapters 4, 5, and 6 to a set of different developments in order to further validate these discoveries as well as to generate data for use in the regression analysis.

Table 6.3 Willets Point Development Entropy Index

Variation Bound	Percent of Total									Entropy Index
	Resi.	Office	Dest. Retail	Local Retail	Conv. Ctr.	Movie Theat.	Hotel	Com. Facility	School	
50%	64.3%	3.8%	11.7%	8.5%	1.9%	0.4%	4.6%	1.5%	3.3%	0.584
45%	62.6%	6.3%	11.9%	8.0%	2.1%	0.4%	3.3%	2.1%	3.2%	0.606
40%	59.8%	4.5%	13.9%	7.6%	2.3%	0.5%	6.4%	2.0%	3.1%	0.633
35%	59.9%	4.9%	13.7%	7.5%	2.5%	0.5%	6.1%	1.9%	3.0%	0.633
30%	59.4%	8.3%	12.6%	7.4%	2.7%	0.5%	4.3%	1.9%	2.9%	0.641
25%	57.8%	8.2%	13.4%	7.1%	2.9%	0.6%	5.5%	1.8%	2.8%	0.656
20%	57.9%	7.0%	14.4%	6.8%	3.1%	0.6%	5.8%	1.7%	2.7%	0.653
15%	58.5%	7.3%	14.9%	6.6%	3.3%	0.7%	4.6%	1.7%	2.5%	0.644
10%	57.9%	6.8%	15.8%	6.3%	3.5%	0.7%	5.2%	1.6%	2.4%	0.648
5%	57.2%	7.1%	16.3%	6.0%	3.7%	0.7%	5.1%	1.5%	2.3%	0.652

CHAPTER 7

STATISTICAL ANALYSIS AND VALIDATION OF THE MODEL RESULTS

7.1 Introduction

Chapters 4 through 6 described a test case of the GA on the Willets Point Development in Queens, New York. The chapters showed that the GA is an effective tool in developing optimized land use mixes and sizes by minimizing vehicle trips and maintaining a similar amount of person trips as an initial area while also providing additional benefits in terms of parking reduction, environmental quality, and safety. However, as the GA requires an initial land use program to function, it is not enough in a case where a developer does not have an initial idea of what to build. Chapter 7 will use the GA on a set of nine additional developments, one of which has two development scenarios, in order to generate data points while Chapter 8 will perform regression analysis on these data points with respect to the neighborhood characteristics in order to create a model that is universal and adaptable to all situations.

7.2 Developments

The developments analyzed in this chapter are located within the five boroughs of New York City in order to take advantage of the large quantities of data available there (New York City Mayor's Office of Environmental Coordination, 2013), (New York City Department of City Planning, 2018), and the trip generation factors for each development are listed in Appendix B. The neighborhood characteristics of these developments have been selected to represent a diverse variety of typical urban conditions. The methodology that was developed to optimize the mix of land uses and its sizes was extended to nine additional developments to further validate the methodology and travel behavior of land uses. In addition, the optimized datasets from the additional developments are used in developing the mathematical model in Chapter 8. It should be noted that each of these developments went through New York City's stringent regulatory environmental review process involving the National Environmental Policy Act (NEPA), State Environmental Review Act (SEQRA), and City Environmental Quality Review (CEQR) which includes transportation analyses and trip generation. The travel demand factors from these environmental reviews were used in this research. These trip generation factors have been examined closely by the city and validated before they could be used for analysis so as to avoid any potential legal issues. The methodology in obtaining these travel demand factors is shown in Section 7.2.1, and the developments themselves are as follows:

- Domino Sugar Redevelopment – This approximately 2.8 million square foot project is located in Williamsburg, Brooklyn along the East River on the site of the former Domino Sugar processing plant. It includes residential, local retail, office, medical office, museum, supermarket and ice rink uses. The neighborhood surrounding Domino Sugar is rapidly gentrifying with a mix of residential and commercial uses.

- East 126th Street Memorial and Mixed-Use Project – This project involves taking one city block in East Harlem occupied by a former MTA bus depot and converting it into a mixed-use development. This 1.1 million square foot project includes residential, local retail, destination retail, office, community facility, and museum uses. This block is located adjacent to major highways and is located away from the dense residential section of East Harlem.

- Gateway Estates II – this approximately 4 million square foot mixed-use development is located in a transit starved area of southeastern Brooklyn near the border with Queens. The project includes residential, local retail, destination retail, day care, and school uses. This low-density neighborhood is being developed in phases and is near a highway.

- Inwood Rezoning – this project involves a major upzoning of the entire Inwood neighborhood in northern Manhattan. This 5.7 million square foot rezoning is expected to include residential, local retail, destination retail, industrial, medical office, library, house of worship, school, FRESH supermarket, community facility, and office uses. This neighborhood is served by two subway lines and has a residential west and an industrial east. It should be noted that the Food Retail Expansion to Support Health (FRESH) program is a tax rebate program that promotes supermarkets in underdeveloped communities *(10)*.

- Jerome Avenue Rezoning – this 4.9 million square foot project involves the redevelopment of auto repair shops along a long section of a subway line in the Bronx into various uses including residential, local retail, destination retail, office, restaurant, FRESH supermarket, medical office, house of worship, day care, and school uses. The neighborhoods around Jerome Avenue are mainly residential with some commercial streets.

- La Central – This is a community oriented development in the Hub section of the Bronx near a major subway station that focuses on community development. This 1.1 million square foot development consists of residential (focusing on supportive housing for the chronically homeless and mentally ill), local retail, health club, office, community facility, day care, TV studio, and music studio/rehearsal space uses. The Hub is one of the major commercial districts in the Bronx and also has a number of residences.

- Silvercup West – This 2.3 million square foot development in Queens along the East River waterfront includes residential, local retail, health club, office, museum, and commercial studio uses. This neighborhood is mainly residential with some industrial uses as well.

- New Stapleton Waterfront Redevelopment – This 1.3 million square foot development in northeastern Staten Island on the waterfront includes residential, retail, restaurant, and office uses. This development is located in an isolated section of the Stapleton neighborhood and is mostly industrial.

- Western Rail Yards – this 6.3 million square foot project is part of the Hudson Yards redevelopment and specifically includes one block in Manhattan between Eleventh and Twelfth Avenues. Two scenarios were analyzed – one with a hotel and one with office space. Other land uses include residential, local retail, destination retail, and school. This development is located on the west side of Midtown Manhattan and the surrounding neighborhood is mostly commercial and event space.

In order to make the model as adaptable as possible, the sample of projects includes a variety of sizes and travel demand characteristics. For example, Gateway Estates II is far from any rail transit and close to a highway. Conversely, the Western Rail

Yards is in Midtown Manhattan with access to various kinds of transit. In addition, La Central is in a very poor neighborhood in the Bronx with hardly any auto ownership at all. As noted above, these projects all have different of land uses which are very specific and therefore cannot be compared individually. Therefore, the land uses were grouped into four land use types. As noted in Chapter 6, residential and office have their own unique characteristics and were therefore treated as their own land use types. Certain other land uses tended to have lower rates of auto mode share and include uses local retail, school, community facilities, houses of worship, and health clubs. These land uses were assigned the land use type "neighborhood." Conversely, uses like destination retail, supermarket, museum, movie theater, and event space tended have a higher auto mode share and were assigned the land use type "destination." Hotel was also assigned to the destination land use type because it is not a common land use type, even though the Willets Point Redevelopment showed it as fluctuating randomly.

7.2.1 Obtaining Verifiable Trip Generation Factors and Data Sources for Developments

Real data was obtained for two purposes. This chapter describes how nine sample developments were selected to not only validate the case study described in Chapters 4 through 6 but to also obtain optimized vehicle trips that can be used as data points for the dependent variable in my linear regression analysis in Chapter 8. The optimized vehicle trips obtained in Chapter 7 are partly based on travel demand factors. These travel demand factors are based on actual data obtained in the field, for existing functioning developments, that resemble and have the characteristics of the proposed projects. In Chapter 8, I used neighborhood characteristics as the independent variable for my linear regression model. These neighborhood characteristics are based on real data as well.

The **travel demand factors** (TDFs) such as trip generation rates, temporal distribution, modal and directional splits, and vehicle occupancy rates are used in developing a model for this research. The TDFs for the nine sample developments come directly from their approved environmental review documents. These studies have been heavily scrutinized by NYCDOT and were subsequently approved. Most of the TDFs for these developments come from the 2014 *City Environmental Quality Review (CEQR) Technical Manual*. The *2014 CEQR Technical Manual* is considered as the holy grail for TDFs in New York City, and provides trip generation rates and temporal distributions that are based on numerous real data collection efforts around the city. Therefore, these rates are updated frequently. When the TDF for a certain land use type is not listed in the *2014 CEQR Technical Manual,* it is industry standard practice either to use surveys that have already been conducted or conduct original surveys so long as the land uses and neighborhood characteristics from these surveys are similar to what is being proposed. The TDFs used in my nine sample developments followed this practice.

For example, for the New Stapleton Waterfront Redevelopment office land use, travel demand factors were sourced from the *Long Island City EIS*, which conducted its own original survey at the nearby Citibank building. Similarly, for the East 126th Street Memorial and Mixed-Use project local retail land use, travel demand factors were taken from surveys on the Lower East Side of Manhattan. For the La Central project health club land use, travel demand factors were taken from data obtained from the Chinatown YMCA. For the Gateway Estates II project, destination retail travel demand factors were obtained from nearby shopping centers. All trip generation factors used for the nine case studies are shown in Appendix B. All rates must be approved by NYCDOT. Before any data collection for existing traffic analysis may be performed, NYCDOT must receive a memo detailing travel demand factors used in trip generation and must approve the rates used. Table 1 provides links to locations where the supporting documents are accessible for each of the nine sample developments. These memos/documents are typically attached to FEIS documents as appendices.

In order to develop a universally adaptable and parsimonious model to assess the optimal mix of land uses and sizes, neighborhood characteristics (independent variables) and vehicle trips (dependent variable) were used for linear regression in Chapter 8. As noted previously, the vehicle trips are partly based on travel demand characteristics. Neighborhood characteristics were chosen because they can be adapted universally, and these neighborhood characteristics tend to affect travel demand characteristics. Another advantage of neighborhood characteristics is that, unlike travel demand characteristics, are not pegged to specific land uses.

The neighborhood is defined as the census tracts which were used to determine travel demand characteristics for the development. The neighborhood characteristics include the development area (*DA*, in square feet), the auto ownership rate (*AO*, in vehicles per household), the neighborhood area (*NA*, in square miles), the number of households in the neighborhood (*H*), the household density (*HD*, in households/square mile), the number of jobs in the neighborhood (*J*), the job density (*JD*, in jobs/square mile), and the total density (*TD*, in households + jobs/square mile). It was discovered that auto ownership rate correlates almost perfectly with household income, and therefore auto ownership was used instead of income. These neighborhood characteristics are obtained from authentic and reliable data sources such as Census data such as *American Community Survey (ACS)* and *AASHTO Census Transportation Planning Product (CTPP)*. This data was collected by U.S. Census Bureau through robust door-to-door surveys and interviews and it is calibrated and validated through additional sources such as state Department of Motor Vehicles, the Department of Labor, and tax records. The census data is updated frequently. For example, the *ACS* data is updated annually. The neighborhood characteristics for each of the nine sample developments are listed in Chapter 8.

Table 7.1 Transportation Data for Environmental Reviews

Additional Case Studies	**URL Links**	**Notes / Page #**
Domino Sugar Redevelopment	https://www1.nyc.gov/assets/planning/download/pdf/applicants/env-review/domino_sugar/17_feis.pdf	17-15 to 17-18
East 126th Street Memorial and Mixed-Use Development	https://a002-ceqraccess.nyc.gov/ceqr/ProjectInformation/ProjectDetail/12151-16DME011M	Refer to Appendix VI-Transportation
Gateway Estates II	https://a002-ceqraccess.nyc.gov/ceqr/ProjectInformation/ProjectDetail/5649-07HPD021K	Refer to Appendix VI-Transportation
Inwood Rezoning	https://a002-ceqraccess.nyc.gov/ceqr/ProjectInformation/ProjectDetail/12932-17DME007M	Refer to Appendix VI-Transportation
Jerome Avenue Rezoning	https://www1.nyc.gov/assets/planning/download/pdf/applicants/env-review/jerome-avenue/appende_feis.pdf	Pages 1 to 9
La Central	https://a002-ceqraccess.nyc.gov/ceqr/ProjectInformation/ProjectDetail/11044-15HPD041X	Refer to Appendix VI-Transportation
Silvercup West	https://www1.nyc.gov/assets/planning/download/pdf/applicants/env-review/silvercup_west/ch09_feis.pdf	Pages 9-31 to 9-33
New Stapleton Waterfront Redevelopment	https://a002-ceqraccess.nyc.gov/ceqr/ProjectInformation/ProjectDetail/4600-06DME001R	Refer to Appendix VI-Transportation
Western Rail Yards	https://www1.nyc.gov/assets/planning/download/pdf/applicants/env-review/western_rail/appendix_e.pdf	Pages 5 to 9

7.3 Results

It was discovered that although the reduction in vehicle trips for each land use type was highly variable, all of the developments generated a best mix of land uses and sizes with a variation bound between 15% and 25%. Figures 7.1 through 7.10 show the change of each land use as a function of variation bound. The resulting number of vehicle trips and land use mix for each project for both the initial and optimized areas are shown below in Table 7.2 and Figure 7.11. These vehicle trips are broken out by land use. It was discovered that in the optimized mix of land uses and sizes (Table 7.3):

- Residential area tends to increase slightly, usually by less than 10% of its base area. Silvercup West was a notable exception in which residential area decreased, mainly because it is centered around a large film studio.
- Neighborhood area tends to increase significantly unless the development is being built in a neighborhood that already has an existing residential base.
- Destination area tends to decrease significantly due to the large auto mode share in this land use type, sometimes as high as 50%.
- Office area tends to decrease significantly although not nearly as much as destination area. Exceptions occur in areas that are heavily residential.

Therefore, it can be concluded that the GA results for the sample developments validate the Willets Point Redevelopment conclusions that it is possible to group land uses into the four types as defined in Chapter 6. The GA results for the sample developments also provide data points in terms of optimized vehicle trips, and it should be noted that because the developments were selected for a diversity of sizes and neighborhood characteristics, the number of vehicle trips for each development is variable. The next chapter describes the effort to regress these vehicle trips with neighborhood characteristics in order to generate equations that are adaptable on a regional basis.

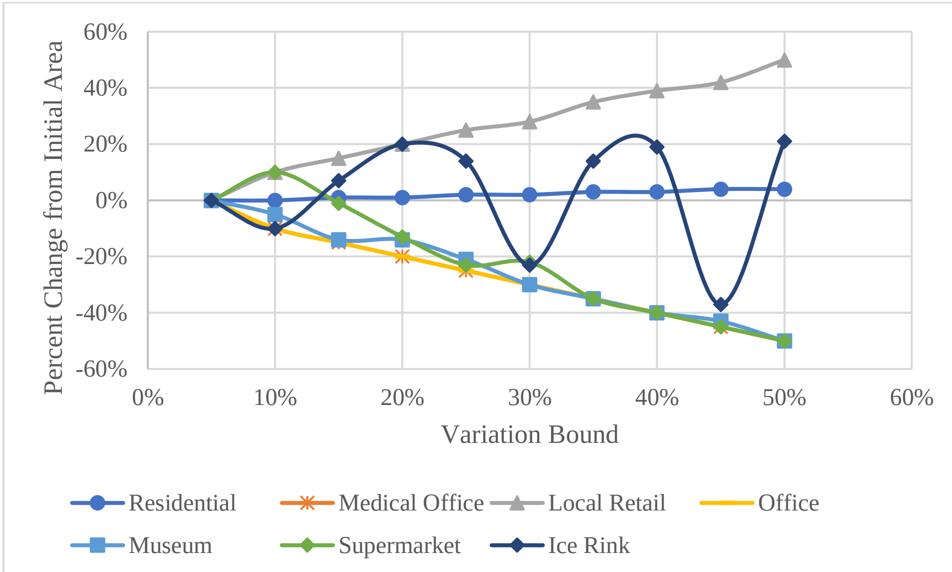


Figure 7.1 Change in land use as a function of variation bound for the Domino Sugar Redevelopment.

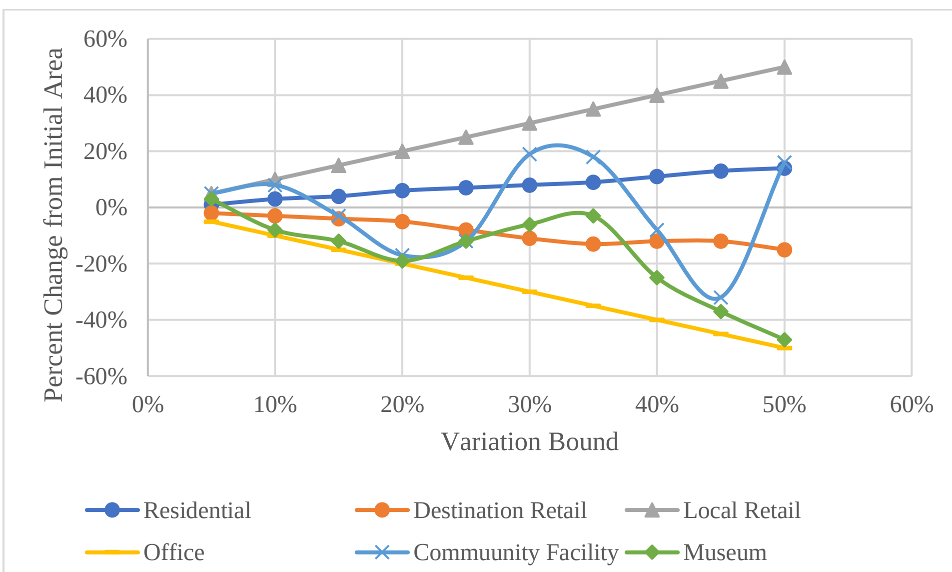


Figure 7.2 Change in land use as a function of variation bound for the 126th Street Memorial and Mixed-Use Project.

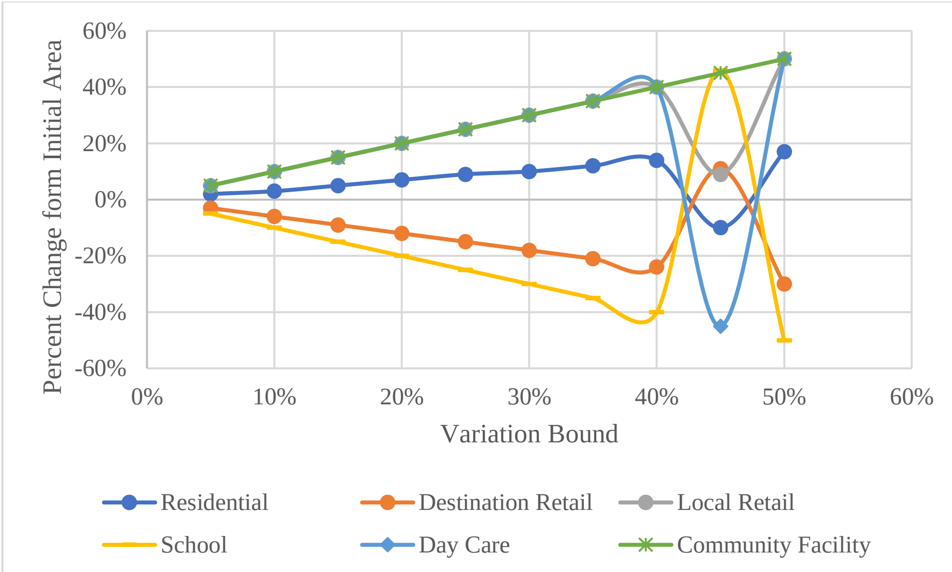


Figure 7.3 Change in land use as a function of variation bound for the Gateway Estates II Project.

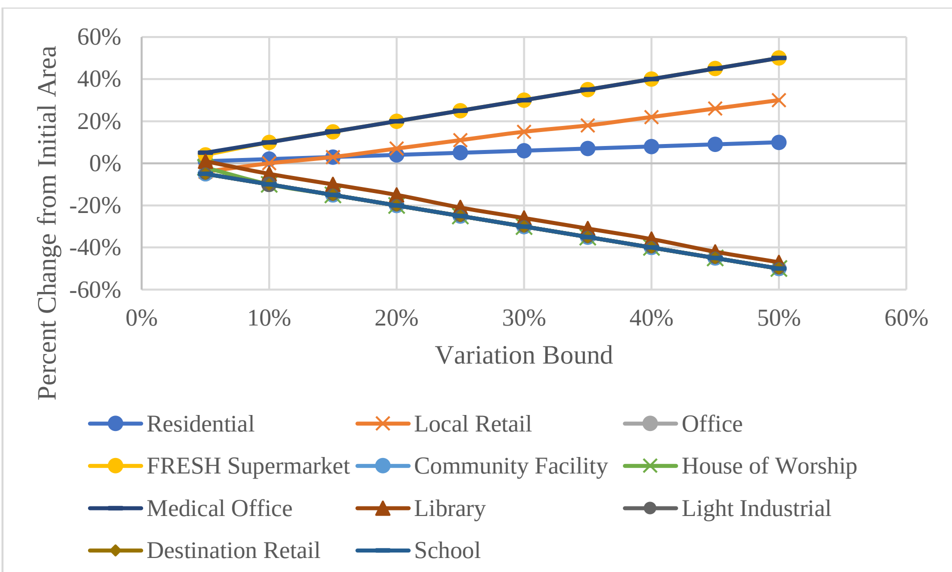


Figure 7.4 Change in land use as a function of variation bound for the Inwood Rezoning Project.

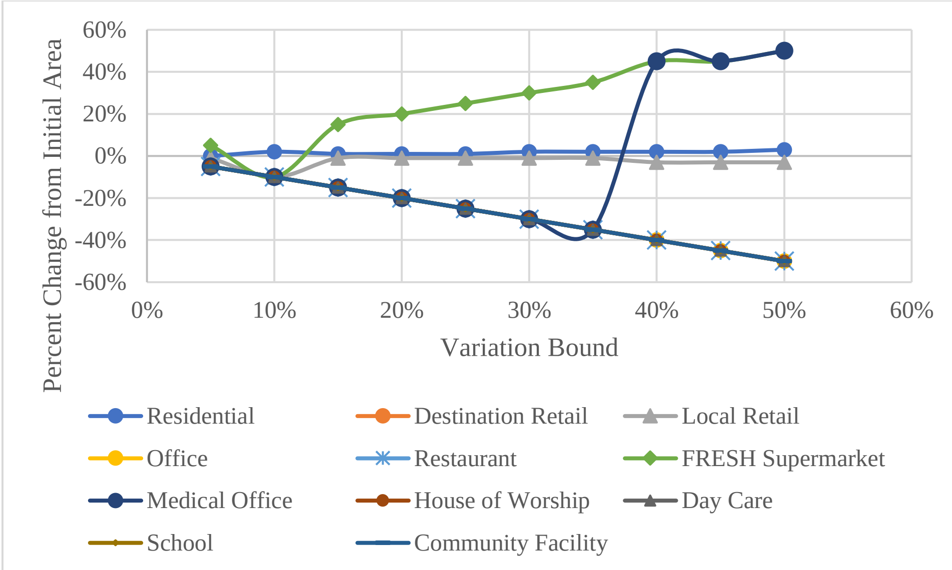


Figure 7.5 Change in land use as a function of variation bound for the Jerome Avenue Rezoning.

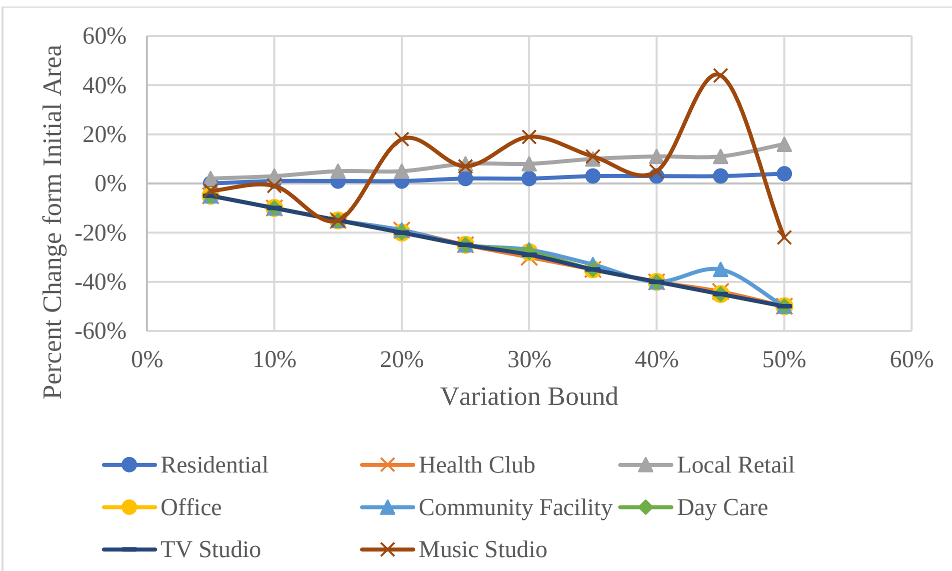


Figure 7.6 Change in land use as a function of variation bound for La Central.

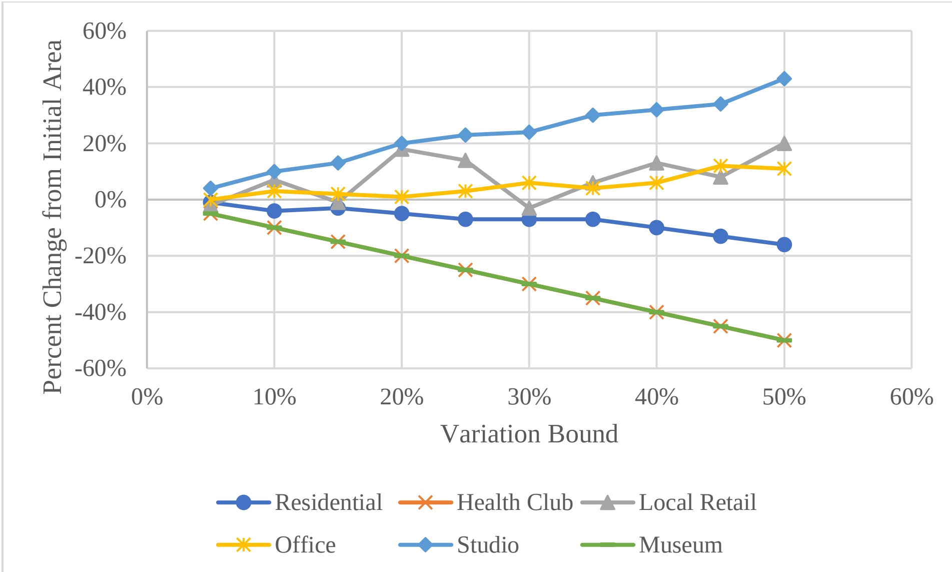


Figure 7.7 Change in land use as a function of variation bound for Silvercup West.

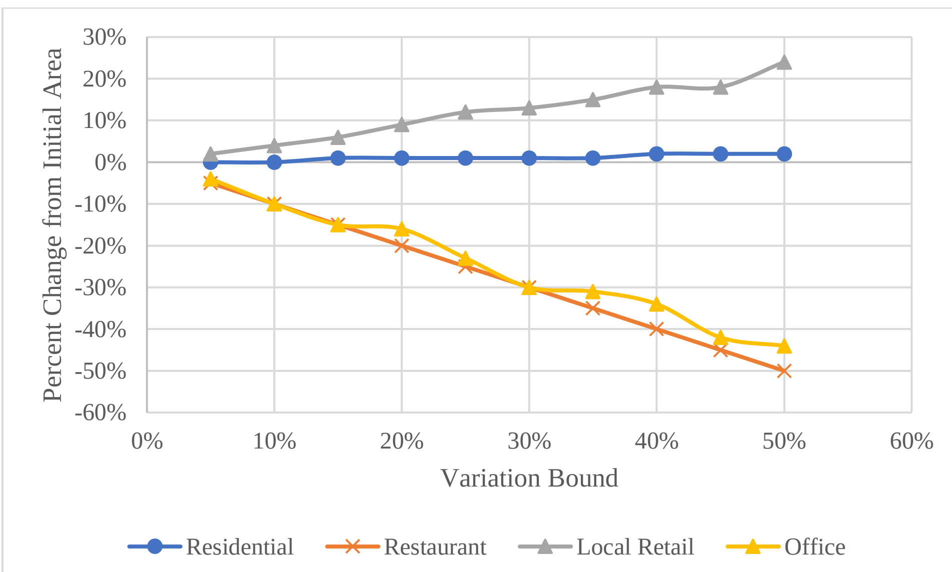


Figure 7.8 Change in land use as a function of variation bound for the New Stapleton Waterfront Redevelopment.

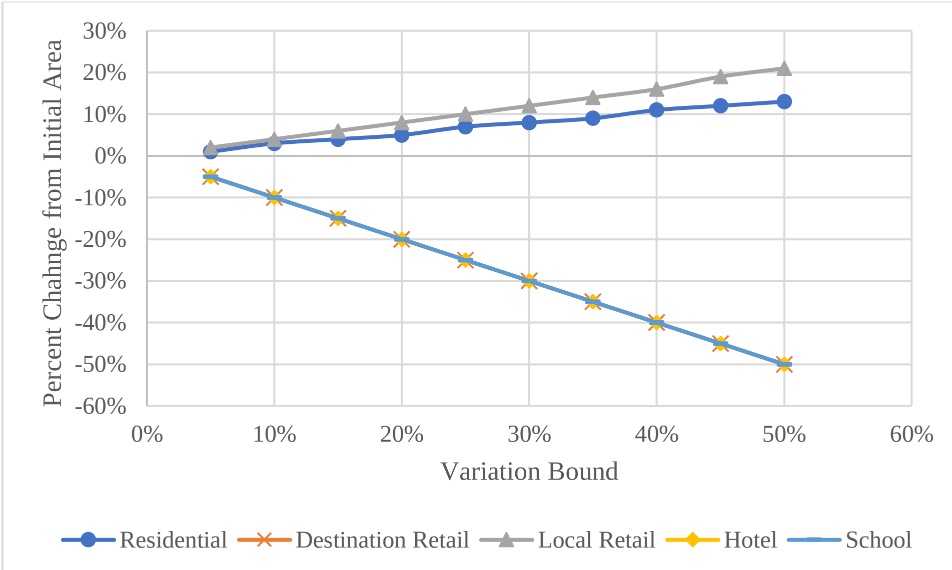


Figure 7.9 Change in land use as a function of variation bound for the Western Rail Yards Hotel Option.

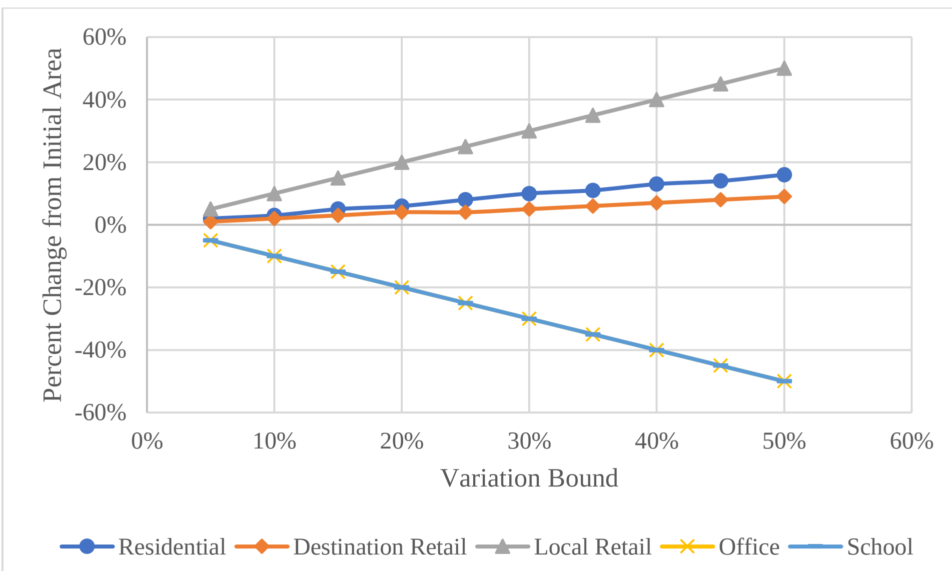


Figure 7.10 Change in land use as a function of variation bound for the Western Rail Yards Max Residential Option.

Table 7.2 Initial and Optimized Development Area and Vehicle Trips

Project	Initial Development Area (ksf)					Initial Vehicle Trips				
	Residential	**Neighborhood**	**Destination**	**Office**	**Total**	**Residential**	**Neighborhood**	**Destination**	**Office**	**Total**
Domino Sugar Redevelopment	2,390.8	166.8	83.4	139.0	2,780.0	262	83	240	148	733
East 126th Street Memorial and Mixed-Use Project	731.0	43.0	96.8	204.3	1,075.0	77	21	45	55	198
Gateway Estates II	2,376.0	316.8	1,267.2	N/A	3,960.0	1,331	224	3,164	N/A	4,719
Inwood Rezoning	4,396.7	628.1	114.2	571.0	5,710.0	482	272	55	340	1,149
Jerome Avenue Rezoning	4,152.3	635.1	48.9	48.9	4,885.0	571	227	51	36	885
La Central	996.8	89.6	22.4	11.2	1,120.0	57	11	9	6	83
Silvercup West	992.2	112.8	473.6	676.5	2,255.0	53	50	186	52	341
New Stapleton Waterfront Redev.	1,096.5	102.0	N/A	76.5	1,275.0	325	242	N/A	84	651
Western Rail Yards - Hotel Option	4,818.4	253.6	1,268.0	N/A	6,340.0	138	116	52	N/A	306
Western Rail Yards - Max Res. Option	4,465.9	251.6	62.9	1,509.6	6,290.0	128	52	23	221	424
Willets Point Development	5,824.0	936.0	2,808.0	832.0	10,400.0	1,263	847	4,347	877	7,334
Project	**Optimized Development Area (ksf)**					**Optimized Vehicle Trips**				
	Residential	**Neighborhood**	**Destination**	**Office**	**Total**	**Residential**	**Neighborhood**	**Destination**	**Office**	**Total**
Domino Sugar Redevelopment	2418.6	194.6	55.6	111.2	2780.0	267	72	200	117	656
East 126th Street Memorial and Mixed-Use Project	774.0	64.5	86.0	150.5	1075.0	82	26	41	44	193
Gateway Estates II	2534.4	316.8	1108.8	N/A	3960.0	1,422	278	2,848	N/A	4,548
Inwood Rezoning	4625.1	571.0	57.1	456.8	5710.0	508	246	43	267	1,064
Jerome Avenue Rezoning	4201.1	586.2	48.9	48.9	4885.0	579	223	40	29	871
La Central	1008.0	89.6	11.2	11.2	1120.0	58	11	8	5	82
Silvercup West	924.6	112.8	518.7	699.1	2255.0	50	43	162	55	310
New Stapleton Waterfront Redev.	1096.5	114.8	N/A	63.8	1275.0	328	213	N/A	67	608
Western Rail Yards - Hotel Option	5072.0	317.0	951.0	N/A	6340.0	148	51	91	N/A	290
Western Rail Yards - Max Res. Option	4780.4	314.5	62.9	1132.2	6290.0	139	56	24	173	392
Willets Point Development	6240.0	1144.0	2288.0	728.0	10400.0	1,339	1,079	3,550	789	6,757

Table 7.3 Percent Difference from Optimized Mix of Land Uses and Sizes to Initial Area

Project	Development Area				Vehicle Trips			
	Residential	**Neighborhood**	**Destination**	**Office**	**Residential**	**Neighborhood**	**Destination**	**Office**
Domino Sugar Redevelopment	1%	17%	-33%	-20%	2%	-13%	-17%	-21%
East 126th Street Memorial and Mixed-Use Project	6%	50%	-11%	-26%	6%	24%	-9%	-20%
Gateway Estates II	7%	0%	-13%	N/A	7%	24%	-10%	N/A
Inwood Rezoning	5%	-9%	-50%	-20%	5%	-10%	-22%	-21%
Jerome Avenue Rezoning	1%	-8%	0%	0%	1%	-2%	-22%	-19%
La Central	1%	0%	-50%	0%	2%	0%	-11%	-17%
Silvercup West	-7%	0%	10%	3%	-6%	-14%	-13%	6%
New Stapleton Waterfront Redevelopment	0%	13%	N/A	-17%	1%	-12%	N/A	-20%
Western Rail Yards - Hotel Option	5%	25%	-25%	N/A	7%	-56%	75%	N/A
Western Rail Yards - Max Residential Option	7%	25%	0%	-25%	9%	8%	4%	-22%
Willets Point Development	7%	22%	-19%	-13%	6%	27%	-18%	-10%

Figure 7.11 Initial and optimized area comparison.

CHAPTER 8

LINEAR REGRESSION RESULTS

8.1 Introduction

The previous chapters described the GA methodology used to obtain a dataset of optimized mixes of land uses and sizes and the resulting vehicular trip generation for various developments around New York City. However, this methodology is not directly adaptable to real world situations because it requires an initial mix of land uses and sizes to be known and requires knowledge of advanced programming. In order to create a model that is universally adaptable on a regional level, it was desirable to perform stepwise regression analysis on the optimized vehicle trips obtained in Chapter 7 using the methodology described at the end of Chapter 4. The result is two sets of equations showing vehicle trips as a function of neighborhood characteristics:

1. The "unified model" shows the total number of vehicle trips a development should generate with its optimized mix of land uses and sizes.
2. The "land use set" is a series of four equations, one for each land use type as described in Chapters 6 and 7, that, together, will give the percent split as to how many vehicle trips should be assigned to each of the four land use types: residential, neighborhood, destination, and office.

   The neighborhood characteristics for each project are shown in Table 8.1.

Table 8.1 Neighborhood Characteristics for Each Project

Project	**Project Area (1,000 sf)**	**Auto Ownership (vehs/Household)**	**Households (Dwelling Units)**	**Neighborhood Area (sq mi)**	**Household Density (House/sqmi)**	**Jobs**	**Job Density (Jobs/sqmi)**	**Total Density (Jobs+House / sqmi)**
Domino Sugar Redevelopment	2,780	34.68%	3,535	0.34	10,397.06	4,385	12,897.06	23,294.12
East 126th Street Memorial and Mixed-Use Project	1,075	17.42%	6,612	0.47	14,068.09	7,500	15,957.45	30,025.53
Gateway Estates II	3,960	48.75%	13,985	2.83	4,941.70	7,845	2,772.08	7,713.78
Inwood Rezoning	5,710	31.22%	22,660	1.34	16,910.45	15,420	11,507.46	28,417.91
Jerome Avenue Rezoning	4,885	28.51%	27,435	0.86	31,901.16	14,245	16,563.95	48,465.12
La Central	1,120	17.04%	575	0.1	5,750.00	2,275	22,750.00	28,500.00
Silvercup West	2,255	37.29%	9,058	1.85	4,896.22	38,860	21,005.41	25,901.62
New Stapleton Waterfront Redevelopment	1,275	74.26%	6,173	3.01	2,050.83	9,725	3,230.90	5,281.73
Western Rail Yards - Hotel Option	6,340	23.44%	2,863	0.96	2,982.29	45,995	47,911.46	50,893.75
Western Rail Yards - Max Residential Option	6,290	23.44%	2,863	0.96	2,982.29	45,995	47,911.46	50,893.75
Willets Point Development	10,400	52.97%	18,538	3.1	5,980.00	25,250	8,145.16	14,125.16

8.2 Results

8.2.1 The Unified Model

In order to develop a unified model, a standard linear model is considered in terms of a forward stepwise linear model which maximizes the incremental variance explained by the neighborhood characteristics at each step for the total number of vehicles. The model should be in the form of the following equation:

$$v = f(PA,AO,NA,H,HD,J,JD,TD) + U \qquad (8.1)$$

Where U is a random (stochastic) variable that has well-defined probabilistic properties and which is surrogate for all those variables that are omitted from the model but that collectively affect the dependent variable.

The first step is to check the outlier assumption in the data. Table 8.2 uses the results of outlier detection based on Cook's Distance, which is used in regression analysis to find influential outliers in a set of predictor variables which is calculated by removing the ith data point from the model and recalculating the regression. A Cook's Distance greater than 1 indicates an influential value, but one may want to look at values above 0.5. The Cook's distance for Willets Point Development (the only development with outliers) was 0.557 which is highly influential in the model computations, which may distort the model accuracy. The variables are transformed to remove this influence. For the analysis, the transformed variables are included instead of original variables. It should be noted that the transformations should be unique to each region this analysis is performed on.

The next step is to use the Statistical Package for Social Sciences (SPSS) to perform forward stepwise regression. This will select the 'best' model from the models with different combination of variables i.e. dependent and independent variables. This selection is based on the AIC as noted in Chapter 4. Models with lower values of AIC have better fit to a data. Figures 8.1, 8.2, and 8.3 show the result of the model building method using the information criterion in the case of this research, which focuses on New York City. As shown in Figure 8.2, the first step of the model selected *NA* as the starting variable because it had the highest variance and the AIC was 165.926. In step 2, *DA* was added to the model because it had the largest reduction in R-squared. The AIC decreased to 164.727. In the third step, *TD* was added because it was had the largest reduction in the coefficient of determination of any variables not in the model. The AIC decreased to 161.550. In Step 4, *NA* was removed from the model because it was shown to be an insignificant variable and to eliminate multicollinearity. The AIC decreased to 156.370. Attempting to add an additional variable to the model increased the AIC and therefore the model terminated and it was determined that vehicle trips in the New York City model would be a function of DA and TD. As shown in Table 8.3, the results fitted a model with an approximate accuracy of 81.4%.

It is further noted from Figure 8.4 that, in the case of the New York City focus, the project area transformed and total density transformed among the other considered variables shows significant predictor importance as 0.58 and 0.42, respectively for the target variable total vehicle trips. In the case of New York City, the unified model is as follows:

$$v' = 1533.94 + 0.590DA' - 0.090TD' \qquad (8.2)$$

where v' is the transformation of vehicle trips, PA' is the transformation of development area, and TD' is the transformation of total density.

Target: total_vt

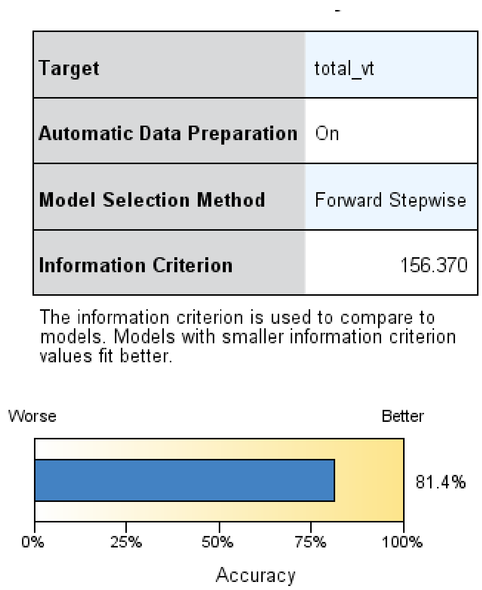
Field	Role	Actions Taken
(auto_ownership_transformed)	Predictor	Trim outliers
(hoshold_density_transformed)	Predictor	Trim outliers
(households_transformed)	Predictor	Trim outliers
(job_density_transformed)	Predictor	Trim outliers
(jobs_transformed)	Predictor	Trim outliers
(neighbourhood_area_transformed)	Predictor	Trim outliers
(project_area_transformed)	Predictor	Trim outliers
(total_density_transformed)	Predictor	Trim outliers

Figure 8.1 Automatic data preparation. Note that if the original field name is X, then the transformed field is displayed as X_transformed. The original field is excluded from the analysis and the transformed field is included instead.

Target: total_vt

		Step			
		1	2	3	4
Information Criterion		165.926	164.727	161.550	156.370
Effect	neighbourhood_area_transformed	✓	✓	✓	
	project_area_transformed		✓	✓	✓
	total_density_transformed			✓	✓

Figure 8.2 Model building summary. Note that the model building method is a forward stepwise method using AIC. A checkmark means the variable is in the model at a certain step.



Target	total_vt
Automatic Data Preparation	On
Model Selection Method	Forward Stepwise
Information Criterion	156.370

Figure 8.3 Model summary.

Several unique discoveries can be made from Equation 8.2. It shows that as the density increases, the total number of vehicle trips decreases. This makes sense for a dense city like New York with a robust transit system. In order to correct for negative vehicle trips, the constant term in this equation is set high. As such, care should be made in selecting neighborhood area (a factor in total density) so that the number of vehicle trips is valid. Lastly, a larger development area will attract more vehicle trips.

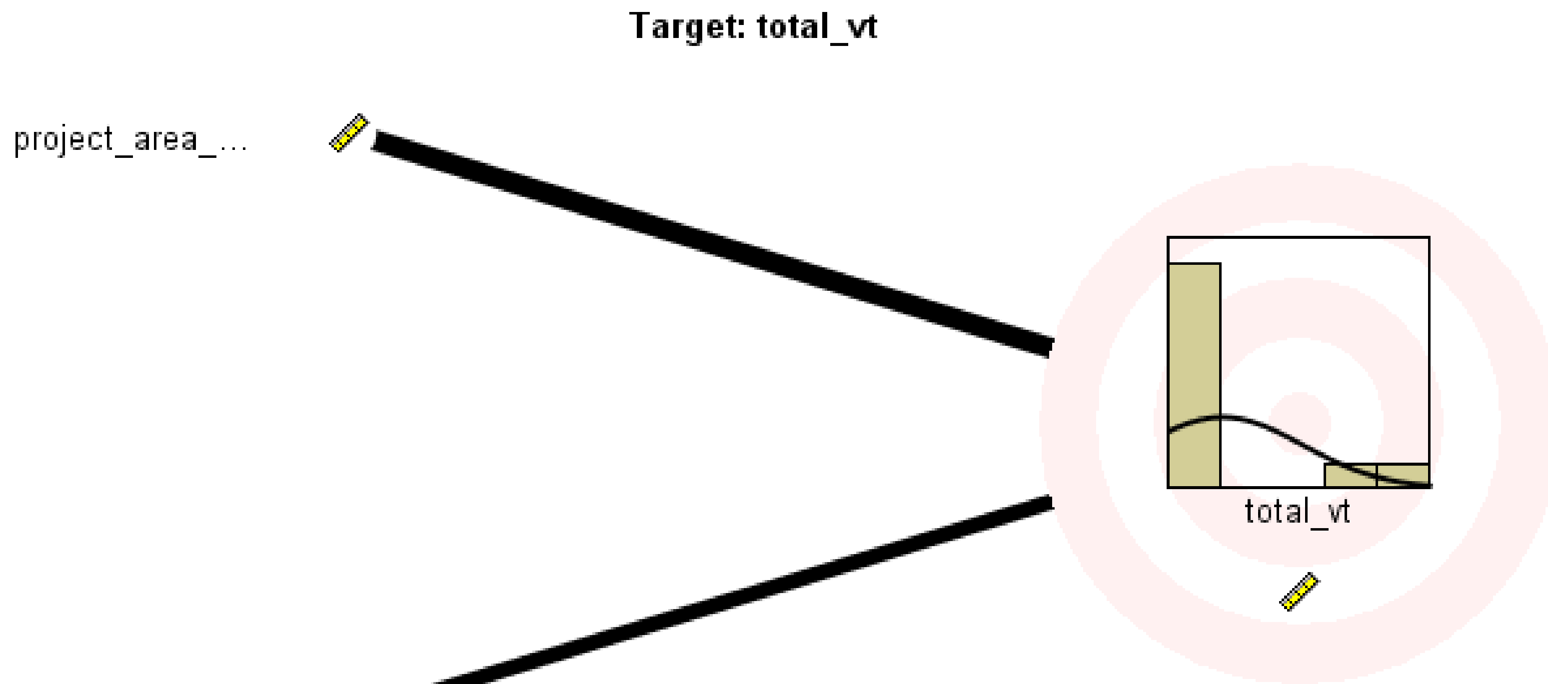


Figure 8.4 Effects of dependent variables on independent variables.

8.2.2 The Land Use Set

The Statistical Package for Social Sciences (SPSS) is used to perform forward stepwise regressions of vehicle trips for each land use type (residential, neighborhood, destination, office) with respect to each neighborhood characteristic. For each iteration, the software output a matrix of Pearson correlation coefficients (PCCs) for each land use type as related to neighborhood characteristic, all of which are shown in Table 8.2. The neighborhood characteristic(s) with the highest PCC relative to vehicle trips is selected to be the independent variable for each land use type. An Analysis of Variance (ANOVA) test is conducted and the statistical significance is obtained. This is an important metric because the model terminates if the statistical significance exceeds 0.05.

Table 8.2 Regression Analysis Results

	Neighborhood Characteristic	**Residential**	**Neighborhood**	**Destination**	**Office**
Pearson Correlation Coefficient	DA	0.553	0.733	0.567	0.760
	AO	0.513	0.505	0.447	0.307
	H	0.580	0.515	0.327	0.363
	NA	0.694	0.659	0.682	0.449
	HD	0.049	-0.009	-0.215	-0.074
	J	-0.195	0.003	-0.059	0.143
	JD	-0.546	-0.413	-0.421	-0.213
	TD	-0.499	-0.402	-0.524	-0.246
R		0.694	0.934	0.682	0.867
R^2		0.482	0.872	0.465	0.752
F		8.372	10.445	7.829	12.338
Statistical Significance		0.018	0.010	0.021	0.007
VIF		N/A	1.046	N/A	1.048

Note: The PCCs highlighted in red represent the neighborhood characteristics that were used in Equations 8.3 through 8.6. It should be noted that the PCCs in the matrix are shown for the first iteration only; the final PCC is shown in the R row.

For equations that have multiple independent variables, the variance inflation factor (VIF) was calculated to ensure that multicollinearity is not present. A VIF of 1 indicates no multicollinearity and the higher the VIF is, the more multicollinear the equation is. The following correlations resulted, and Table 8.5 shows their coefficients of determination:

- Residential and Destination vehicle trips were highly correlated with *NA*.
- Neighborhood vehicle trips were highly correlated with *DA* and *JD*.
- Office vehicle trips were highly correlated with *DA* and *TD*.

As shown in Table 8.5, all results are statistically significant and multivariable equations have a low VIF and are therefore not multicollinear. Based on these results, a methodology described in Hair et al. is used to generate regression equations that can be used universally (Hair et al., 2010). This is a stepwise procedure that maximizes the incremental explained variance at each step. This methodology resulted in the following equations:

$$v = 312.098NA - 1.581 \tag{8.3}$$

$$v = 0.09DA - 0.012JD + 52.528 \tag{8.4}$$

$$v = 793.225NA - 508.802 \tag{8.5}$$

$$v = 0.068DA - 0.006TD + 30.077 \tag{8.6}$$

Taking the vehicle trips from Equations 8.3, 8.4, 8.5, and 8.6 and diving each by the sum of the vehicle trips from the four equations gives the percent of the development that should be assigned to the residential, neighborhood, destination, and office land use types respectively. Each percentage should be multiplied by the total number of vehicle trips obtained from the unified model to obtain the number of vehicle trips that should be assigned to each land use types. Using existing travel demand characteristics from traditional trip generation, the approximate area of each land use type can be obtained by multiplying by vehicle occupancy and dividing by the vehicle trip mode share, the peak hour temporal distribution, and the trip rate per unit area.

It should be noted that it is quite possible, perhaps even probable, that the resulting area would not be the total development area. At this point, good engineering judgment should be made to determine which individual land uses should make up the neighborhood and destination land use types so that the total development area is approximately what the development expects and the total number of vehicle trips is approximately what the unified model produces.

It should be noted that in some cases Equations 8.3 through 8.6 could result in negative vehicle trips. This could result in the surrounding neighborhood selected for modeling having too small of an area. This is particularly true regarding the destination land use type especially because destination type land uses tend to draw from the region as a whole rather than from the surrounding neighborhoods. In addition, developments with large neighborhood areas tend to overestimate the percent area that should be residential and/or destination. For these reasons, it was discovered that engineering judgment should be exercised when determining the neighborhood areas, especially if destination land uses are desirable. In some cases, the destination land use type can be excluded altogether.

The Entropy Indices for the optimized area of each of the sample developments is shown in Table 8.3. As shown in Table 8.3, the optimized areas of each development show a similar or more diverse land use set than in the initial area.

Table 8.3 Entropy Index Comparison

Development	Entropy Index	
	Initial Area	**Optimized Area**
Domino Sugar Redevelopment	0.314	0.370
East 126th Street Memorial and Mixed-Use Project	0.558	0.625
Gateway Estates II	0.528	0.596
Inwood Rezoning	0.391	0.454
Jerome Avenue Rezoning	0.271	0.322
La Central	0.247	0.296
Silvercup West	0.757	0.840
New Stapleton Waterfront Redevelopment	0.393	0.452
Western Rail Yards - Hotel Option	0.368	0.431
Western Rail Yards - Max Residential Option	0.402	0.459
Willets Point Redevelopment	0.658	0.656

CHAPTER 9

CONCLUSION AND FURTHER RECCOMENDATIONS

9.1 Summary

Traffic congestion has always been and will continue to be a problem in metropolitan regions. In recent years, urban planners and engineers have adapted sustainable and equitable growth plans encouraging mixed-use development, transit-oriented development, and "smart" growth in an attempt to reduce traffic congestion. However, there is currently no universally adaptable methodology to creating such a development in a way that reduces vehicular trip generation by optimizing the mix of land uses and sizes in harmony with the surrounding neighborhood characteristics in order to achieve the four "D's" of sustainable growth: Density, Diversity, Design, and Distance to transit. In fact, traditional trip generation methods, which treat each land use as a single entity, continue to be used, and developers will create a mix of land uses and sizes that seeks to maximize profits only without accounting for the needs of other stakeholders such as departments of transportation, elected officials, and local residents and businesses. Most attempts to correct this through research have focused on methods to account for linked, or internal, trips within a mixed-use development and do not attempt to optimize the mix of land uses and sizes.

The goal of this research was to create a methodology on generating an optimal mix of land uses and sizes. This research therefore provides a unique perspective as to how land area should be developed in order to ensure sustainable and equitable growth for a metropolitan region. Instead of pre-selecting land uses, it allows neighborhood characteristics to determine the amount of different types of land uses that should be built in order to minimize vehicle trips while maximizing person trips. It should be noted that neighborhood characteristics are obtained using census data such as the *ACS* and *AASHTO CTPP*. The methodology uses the genetic algorithm (GA) to minimize vehicle trips by altering the land area of existing developments and constraining the change by maximizing the total person trips and keeping the total development area constant. The travel demand characteristics that are put into the GA must be vetted and approved by regional agencies so that they can accurately predict field conditions. In New York City, this is done using criteria detailed in Chapters 4 and 7. Using the discovery that similar types of land uses can be grouped together into four land use types ("residential," "neighborhood," "destination," and "office), forward stepwise linear regression is then used on the resulting optimized vehicular trips from the GA to create equations that show vehicular trips as a function of neighborhood characteristics. By minimizing vehicle trips, impacts to the local and regional roadway networks can be lessened or avoided entirely and while maximizing person trips, developers can continue to maximize economic activity in their developments. Minimizing parking in the developments frees up additional area for revenue-generating land uses as well, and money can be saved from implementing expensive mitigation measures. Using existing neighborhood characteristics around the development ensures a diverse development that the development will attract a large number of local and internal trips and helps to ensure walkability within the development.

This methodology is universally adaptable and readily implementable. This methodology will integrate large developments into the community as well as provide economic opportunity by making sure local people can live, visit, and work. This methodology will take traffic off of nearby streets by building land uses that are compatible with each other. For example, recently, a deal to bring Amazon offices to New York City was killed because of the traffic impacts and because the development was not conducive to the existing neighborhood character. This methodology would have made Amazon's offices friendlier to the surrounding neighborhood (Goodman, 2019).

Although the methodology described in this research is universally adaptable, the final equations as shown in Chapter 8 are not. They are based on travel and neighborhood characteristics in a particular urban area (New York City). Therefore, it is necessary to provide instructions to stakeholders on how to implement this methodology. In addition, the methodology does not take into account recent trends in transportation, including the advent of transportation networking companies (TNCs) such as Uber and Lyft as well as car sharing.

9.2 Implementation of the Methodology

The methodology described above should be implemented regionally. In order to generate the equations to use vehicle trips as a function of neighborhood characteristics, regional planning associations, state departments of transportation, and other associations should work together to do the following:

1. Obtain the necessary software: MATLAB version 7.1 and Statistical Package for the Social Sciences (SPSS).
2. Obtain environmental review documents for mixed-use developments, transit-oriented developments, and "smart" growth developments around the region. Such developments should be from diverse areas within the region in terms of the four "D's" as well a diverse range of development sizes. In addition, obtain the neighborhood characteristics in the surrounding area from census data. A large enough sample size should be used to increase the accuracy of the model.

3. Use MATLAB version 7.1 to run the GA methodology as described in Chapter 4 using the provided code.

4. Obtain the total amount of vehicle trips and the vehicle trips of each land use type from the GA results for each development.

5. Run the SPSS model to obtain equations for the unified model and the land use set.

6. Publish the equations in a regional planning manual.

7. Update the equations every 5-10 years or after a major infrastructure project is complete. This is to account for changes in regional travel behavior.

Engineers should take the equations and do the following for a development:

1. Use the unified model to obtain the total amount of peak hour vehicle trips the development should generate

2. Use the land use set to obtain the percent split of each land use type. Engineers should use their best judgment to determine the size of the neighborhood area so that certain land use types do not take up too much of the development area or are too small to be feasible. Land use types with negative vehicle trips should be excluded.

3. Multiply the result of the unified model by the percentages obtained from the land use set to obtain the number of peak hour vehicle trips each land use type should generate.

4. Use travel demand characteristics to obtain land use area from the peak hour vehicle trips.

5. Fine tune the individual land uses within the neighborhood and destination types to make sure the total development area is correct.

9.3 Recent Trends in Urban Transportation

Because this model bases the optimal mix of land uses and sizes on minimizing vehicle trips in a classical sense, it does not account for recent trends in the transportation industry. In recent years, the proliferation of TNCs such as Uber and Lyft as well as car sharing services such as Zipcar and Enterprise CarShare have changed the way people travel. This phenomenon has affected all kinds of neighborhoods regardless of transit accessibility.

This data has only begun to be collected recently so there is not enough information to create a detailed model. However, recent trends in New York City suggest that there are currently more trips made via TNCs than via traditional taxis. The 2018 *New York City Mobility Report* suggests that of all people who use for-hire vehicle services, approximately 59% used TNCs in 2017 while the remaining 41% use traditional taxis (New York City Department of Transportation, 2018). This was the first year when the number of trips using TNCs was larger than the number of trips using taxis in NYC. The report also showed that the number of trips using TNCs in 2017 increased 71% over 2016 (the first two years this data has been collected), and the vast majority of TNC riders would have used either transit (50%) or traditional taxis (43%), although there is significant overlap because the survey allowed multiple options to be selected. Table 9.1 shows the full results of this survey and an estimated result with no overlap which shows a sum of 100% (mode-capture rate).

Table 9.1 New York City Mode-Capture Percentages for TNCs

Previous Mode	Survey Results	Estimated Results (No Overlap)
Transit	50%	41%
Taxi	43%	35%
Walk	13%	10%
Auto	12%	10%
Bike	3%	2%
Would not make the trip	2%	2%

The 2017 *Citywide Mobility Survey* suggest that 35% of New Yorkers utilize at least one TNC Membership in TNCs is most common in locations closer to the Manhattan CBD with Queens being the most popular borough for TNCs (New York City Department of Transportation, 2017). It also shows that the most popular use for TNC trips is for social and recreational trips (46% of respondents), with 27% saying they use it for commuting to work, although there is overlap. Table 9.2 shows the raw results and the estimated results with no overlap that shows a sum of 100% (purpose-capture).

Table 9.2 New York City Purpose-Capture Percentages for TNCs

Trip Purpose	**Survey Results**	**Estimated Results (No Overlap)**
Social/Recreation	46%	31%
Commute	27%	18%
Personal Errands	27%	18%
Medical	13%	9%
Business	11%	7%
Shopping	11%	7%
School	6%	4%
Accompanying Others	4%	3%
Other Purpose	4%	3%

This 18% is important because traditional trip generation for residential and office uses utilize census journey-to-work data to determine the trip generation rates during peak travel hours for residential and office uses. However, the Citywide Mobility Survey does not account for the time periods in which TNC users travel. On the other hand, a total of 15% of TNC trips during peak commuting hours in the Boston area would have taken transit (12%) or bicycles (3%) (Gehrke et al., 2018). This indicates that the vast majority of the commuting trips would occur during peak commuting hours. This survey also indicates that roughly 40% of all trips on a typical weekday occur between 7:00 PM and midnight, which implies that in Boston, like in New York, most TNC trips occur for a social or recreational purpose rather than commuting. The Boston survey showed that 59% of TNC trips add new cars to the road. This is less than the New York surveys which showed that 68% of TNC trips add new cars to the road.

Although these surveys do not have a rail vs bus breakdown of the trips taken by transit, independent studies suggest that the transit capture is heavily weighted towards bus ridership, with bus ridership in New York City declining by approximately 9 million, 18 million, and 12 million trips per year between 2013-2014, 2014-2015, and 2015-2016 respectively while subway ridership did not decline until the 2015-2016 year with a loss of approximately 6 million annual trips (Schaller, 2017). This implies that most TNC trips which replace transit replace bus service.

The *Citywide Mobility Survey* breaks down the capture rates by mode and trip purpose further. It includes a regional breakdown of the mode-capture and purpose-capture percentages. This can be used to roughly estimate the mode-capture rate for various land use types. The purpose-capture percentages are grouped into the land use types they apply to as shown below:

- Residential: Commute. Although most of the trip purposes can be applied to the residential use, the commute purpose is used to determine the residential modal split.
- Office: Commute, Business.
- Neighborhood: Social/Recreation, Personal Errands, Medical, School, Other Purpose, Accompanying Others.
- Destination: Social/Recreation, Shopping, Other Purpose, Accompanying Others, Business.

Because there is not enough data to show trends over multiple years, it is too early to develop a mathematical model which indicates the exact percentage of trips which would switch from other modes to a TNC service. For example, the Willets Point Redevelopment would be in Middle Queens. The transit mode capture is 57%. This does not mean peak hour transit trips would be reduced by 57%, so further research would be required. However, it should be noted that there are studies correlating decreasing auto ownership with TNC mode-capture for autos. This is very helpful because it has the potential to reduce the amount of space required for parking. Table 9.3 and Figure 9.1 shows a correlation taking auto ownership rates from the 2010 *American Association of State Highway Transportation Officials Census Transportation Planning Product* (*AASHTO CTPP)* for each of the New York City regions and comparing it to the auto mode-capture for TNC services from the Citywide Mobility Study. As shown in Table 14 and Figure 6, it was discovered that the auto capture rates tend to be higher in outer regions where auto ownership is higher.

Based on the discussion in this chapter, it is recommended to further refine the model based on these recent trends in transportation.

Table 9.3 TNC Auto Capture by New York City Region as a Function of Auto Ownership

Region	**Autos/Household**	**TNC Auto Capture**
Manhattan CBD	0.25	17%
Northern Manhattan	0.26	13%
Southern Bronx	0.33	24%
Northern Bronx	0.76	31%
Inner Brooklyn	0.42	17%
Outer Brooklyn	0.70	17%
Inner Queens	0.59	22%
Middle Queens	0.75	22%
Outer Queens	1.20	22%
Staten Island	1.48	35%

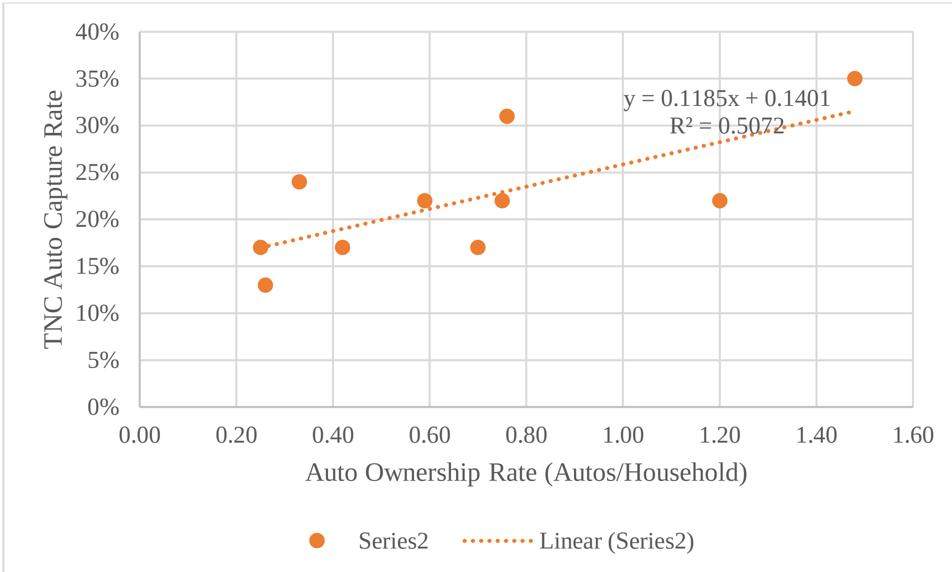


Figure 9.1 TNC auto capture by New York City region as a function of auto ownership.

APPENDIX A

GENETIC ALGORITHM ITERATIONS

Tables A.1 to A.10 show each iteration of the GA for each variation bound.

Table A.1 Run-by-Run Results of the GA for Case 1 (15% Variation Bound)

Run No	Residential	Office	Destination	Retail	Convention	Cinema	Hotel	Community Facility	School	Area (ksf)	Person Trip	Vehicle Trip
1	5851	780	1754	595	398	81	559	149	231	10400	31892	7329
2	5852	779	1753	598	396	77	562	150	233	10400	31860	7311
3	5852	779	1752	599	395	77	562	150	234	10400	31860	7306
4	5852	778	1751	600	394	76	563	152	236	10400	31860	7301
5	5852	778	1750	601	394	75	563	152	236	10400	31868	7299
6	5853	776	1747	603	393	74	563	152	237	10400	31863	7291
7	5854	775	1746	604	391	73	566	153	238	10400	31860	7283
8	5855	775	1743	607	388	72	566	154	239	10400	31861	7273
9	5857	775	1743	609	386	70	565	155	239	10400	31860	7266
10	5857	773	1742	610	386	69	566	157	240	10400	31863	7259
11	5859	771	1742	611	385	68	565	158	240	10400	31860	7255
12	5929	816	1620	667	368	83	498	158	261	10400	32343	7173
13	5932	815	1618	666	367	79	500	159	263	10400	32267	7155
14	5939	814	1612	665	361	75	503	165	264	10400	32151	7121
15	5941	814	1611	664	359	70	509	168	264	10400	32058	7101
16	5943	814	1608	663	357	68	511	172	264	10400	31998	7085
17	5946	812	1606	663	356	68	512	172	264	10400	31983	7079
18	5949	811	1603	664	354	68	515	172	264	10400	31967	7071
19	5949	812	1600	664	354	68	516	172	264	10400	31955	7067
20	5954	812	1597	664	349	68	519	172	264	10400	31920	7055
21	5958	815	1594	662	347	68	519	172	264	10400	31861	7046
22	5960	815	1593	663	344	68	521	172	264	10400	31860	7040
23	5962	814	1591	665	340	68	522	172	264	10400	31865	7034
24	5962	814	1590	665	340	68	523	172	264	10400	31860	7032
25	5963	814	1588	666	340	68	524	172	264	10400	31861	7029
26	5964	814	1588	666	340	68	523	172	264	10400	31860	7028
27	5964	814	1587	666	340	68	523	172	264	10400	31860	7028
28	5964	814	1585	668	340	68	523	172	264	10400	31873	7026
29	5966	813	1585	667	340	68	524	172	264	10400	31864	7025
30	5967	813	1584	667	340	68	524	172	264	10400	31860	7023
31	5967	813	1583	668	340	68	525	172	264	10400	31860	7022
32	5967	812	1583	668	340	68	525	172	264	10400	31860	7022
33	5969	812	1581	669	340	68	524	172	264	10400	31866	7020
34	5970	812	1578	670	340	68	524	172	264	10400	31875	7016
35	5971	812	1577	670	340	68	526	172	264	10400	31860	7014
36	5973	812	1576	670	340	68	525	172	264	10400	31860	7012
37	5974	811	1575	670	340	68	524	172	264	10400	31860	7011
38	5974	811	1575	670	340	68	524	172	264	10400	31860	7011
39	5976	811	1575	670	340	68	522	172	264	10400	31860	7011
40	5976	811	1575	670	340	68	522	172	264	10400	31860	7010
41	5977	811	1575	670	340	68	522	172	264	10400	31860	7010
42	5977	810	1574	671	340	68	523	172	264	10400	31861	7008
43	5978	810	1570	673	340	68	524	171	264	10400	31880	7005
44	5979	810	1569	673	340	68	525	172	264	10400	31874	7003
45	5980	808	1568	673	340	68	526	172	264	10400	31866	7000
46	5981	808	1567	673	340	68	526	172	264	10400	31860	6998
47	5984	806	1564	674	340	68	527	172	264	10400	31860	6993
48	5985	805	1564	675	340	68	527	172	264	10400	31860	6992
49	5985	804	1563	675	340	68	528	172	264	10400	31860	6991
50	5986	804	1563	675	340	68	527	172	264	10400	31860	6990
51	5986	804	1562	675	340	68	527	172	264	10400	31860	6989
52	5986	804	1562	675	340	68	527	172	264	10400	31860	6989
53	5986	804	1561	676	340	68	528	172	264	10400	31861	6988
54	5987	803	1561	676	340	68	529	172	264	10400	31860	6987
55	5988	802	1560	676	340	68	528	172	264	10400	31861	6986
56	5989	802	1559	677	340	68	528	172	264	10400	31871	6985
57	5989	802	1555	678	340	68	531	172	264	10400	31861	6980
58	5991	802	1552	679	340	68	531	172	264	10400	31865	6976
59	5994	799	1550	680	340	68	532	172	264	10400	31863	6971
60	5995	799	1550	680	340	68	531	172	264	10400	31860	6970
61	5998	798	1549	680	340	68	530	172	264	10400	31860	6968
62	6002	797	1546	682	340	68	529	172	264	10400	31872	6964
63	6003	798	1545	682	340	68	529	172	264	10400	31861	6963
64	6005	797	1545	682	340	68	528	172	264	10400	31860	6962
65	6006	797	1544	682	340	68	527	172	264	10400	31860	6961
66	6006	797	1544	682	340	68	527	172	264	10400	31860	6961
67	6008	796	1544	682	340	68	525	172	264	10400	31861	6960
68	6008	796	1544	682	340	68	525	172	264	10400	31860	6959
69	6011	795	1544	682	340	68	523	172	264	10400	31860	6959
70	6011	795	1544	682	340	68	523	172	264	10400	31860	6958
71	6012	795	1544	682	340	68	522	172	264	10400	31860	6958
72	6012	795	1544	682	340	68	522	172	264	10400	31860	6958
73	6013	795	1544	682	340	68	522	172	264	10400	31860	6958
74	6013	795	1544	682	340	68	522	172	264	10400	31860	6958
75	6014	795	1544	682	340	68	521	172	264	10400	31860	6958
76	6014	795	1544	682	340	68	521	172	264	10400	31860	6958
77	6014	795	1544	682	340	68	521	172	264	10400	31860	6958
78	6017	794	1544	682	340	68	518	172	264	10400	31860	6957

79	6018	793	1544	682	340	68	518	172	264	10400	31860	6957
80	6018	793	1544	682	340	68	518	172	264	10400	31860	6957
81	6019	793	1544	682	340	68	517	172	264	10400	31860	6957
82	6020	793	1544	682	340	68	516	172	264	10400	31860	6956
83	6020	793	1544	682	340	68	516	172	264	10400	31860	6956
84	6021	793	1544	682	340	68	515	172	264	10400	31860	6956
85	6021	793	1544	682	340	68	515	172	264	10400	31860	6956
86	6022	792	1544	682	340	68	515	172	264	10400	31860	6956
87	6022	792	1544	682	340	68	515	172	264	10400	31860	6956
88	6024	792	1544	682	340	68	513	172	264	10400	31860	6955
89	6026	792	1544	682	340	68	512	172	264	10400	31860	6955
90	6027	792	1544	682	340	68	511	172	264	10400	31861	6955
91	6028	792	1544	682	340	68	510	172	264	10400	31860	6955
92	6028	792	1544	682	340	68	510	172	264	10400	31860	6955
93	6029	792	1544	682	340	68	509	172	264	10400	31860	6955
94	6029	792	1544	682	340	68	509	172	264	10400	31860	6954
95	6029	792	1544	682	340	68	509	172	264	10400	31860	6955
96	6031	792	1544	682	340	68	507	172	264	10400	31860	6954
97	6031	792	1544	682	340	68	507	172	264	10400	31860	6954
98	6032	791	1544	682	340	68	506	172	264	10400	31860	6954
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100	6033	791	1544	682	340	68	506	172	264	10400	31860	6953
101	6034	790	1544	682	340	68	505	172	264	10400	31860	6953
102	6034	790	1544	682	340	68	505	172	264	10400	31860	6953
103	6035	790	1544	682	340	68	504	172	264	10400	31860	6953
104	6036	790	1544	682	340	68	502	172	264	10400	31860	6953
105	6038	790	1544	682	340	68	501	172	264	10400	31860	6953
106	6038	790	1543	682	340	68	501	172	264	10400	31860	6952
107	6038	790	1543	682	340	68	501	172	264	10400	31860	6952
108	6040	788	1544	682	340	68	500	172	264	10400	31860	6952
109	6042	788	1543	682	340	68	500	172	264	10400	31860	6951
110	6042	788	1543	682	340	68	499	172	264	10400	31860	6951
111	6043	788	1543	682	340	68	498	172	264	10400	31860	6951
112	6044	788	1543	682	340	68	497	172	264	10400	31860	6951
113	6045	786	1544	682	340	68	499	172	264	10400	31860	6950
114	6046	786	1544	682	340	68	498	172	264	10400	31860	6950
115	6046	786	1544	682	340	68	497	172	264	10400	31860	6950
116	6046	785	1544	682	340	68	497	172	264	10400	31860	6950
117	6046	785	1544	682	340	68	497	172	264	10400	31860	6949
118	6046	785	1544	682	340	68	497	172	264	10400	31860	6949
119	6047	785	1544	682	340	68	496	172	264	10400	31860	6950
120	6049	785	1544	682	340	68	495	172	264	10400	31860	6949
121	6050	785	1544	682	341	68	493	172	264	10400	31860	6949
122	6050	785	1544	682	341	68	493	172	264	10400	31860	6949
123	6050	785	1544	682	340	68	493	172	264	10400	31860	6949
124	6050	785	1544	682	340	68	493	172	264	10400	31860	6949
125	6053	785	1544	682	340	68	490	172	264	10400	31860	6949
126	6053	785	1544	682	340	68	490	172	264	10400	31860	6948
127	6054	785	1544	682	340	68	489	172	264	10400	31860	6948
128	6055	784	1545	682	340	68	489	172	264	10400	31860	6948
129	6057	784	1544	682	340	68	488	172	264	10400	31861	6948
130	6058	784	1543	682	340	69	487	172	264	10400	31860	6947
131	6058	784	1543	682	340	69	487	172	264	10400	31860	6947
132	6060	784	1543	682	340	69	485	172	264	10400	31860	6947
133	6062	784	1544	682	340	69	483	172	264	10400	31860	6946
134	6062	784	1544	682	340	69	483	172	264	10400	31860	6946
135	6062	784	1544	682	340	69	483	172	264	10400	31860	6946
136	6063	784	1543	682	340	68	482	173	264	10400	31860	6946
137	6065	784	1543	682	340	68	480	172	264	10400	31860	6946
138	6043	773	1562	677	353	87	480	168	257	10400	32123	7038
139	6046	773	1560	674	349	83	486	167	261	10400	32015	7015
140	6051	774	1558	671	346	79	487	171	263	10400	31900	6992
141	6052	775	1557	671	345	77	486	172	264	10400	31864	6982
142	6053	775	1557	673	344	75	486	172	264	10400	31867	6977
143	6054	775	1556	675	341	74	487	172	264	10400	31871	6970
144	6056	775	1556	677	340	71	488	172	264	10400	31860	6960
145	6058	774	1556	678	340	70	487	172	264	10400	31861	6959
146	6063	773	1553	680	340	68	486	172	264	10400	31861	6949
147	6066	773	1552	681	340	68	484	172	264	10400	31861	6947
148	6067	772	1552	681	340	68	483	172	264	10400	31861	6946
149	6068	772	1552	681	340	68	482	172	264	10400	31860	6946
150	6069	771	1551	681	340	68	483	172	264	10400	31860	6945
151	6070	771	1551	681	340	68	482	172	264	10400	31860	6944
152	6071	770	1551	681	340	68	481	172	264	10400	31861	6944
153	6072	770	1551	681	340	68	480	172	264	10400	31860	6943
154	6073	770	1551	681	340	68	480	172	264	10400	31860	6943
155	6074	770	1551	681	340	68	479	172	264	10400	31860	6942
156	6074	770	1551	681	340	68	479	172	264	10400	31860	6942
157	6074	770	1550	682	340	68	479	172	264	10400	31860	6942
158	6075	770	1550	682	340	68	479	172	264	10400	31860	6941
159	6075	769	1549	682	340	68	480	172	264	10400	31860	6941
160	6075	769	1549	682	340	68	479	172	264	10400	31861	6940
161	6077	769	1549	682	340	68	478	172	264	10400	31860	6940
162	6077	769	1549	682	340	68	478	172	264	10400	31860	6940
163	6077	769	1549	682	340	68	478	172	264	10400	31860	6940
164	6077	769	1549	682	340	68	478	172	264	10400	31860	6940
165	6077	769	1549	682	340	68	478	172	264	10400	31860	6940
166	6078	768	1549	682	340	68	477	172	264	10400	31860	6939
167	6078	768	1549	682	340	68	477	172	264	10400	31860	6939
168	6078	768	1549	682	340	68	477	172	264	10400	31860	6939
169	6078	768	1549	682	340	68	477	172	264	10400	31860	6939
170	6079	768	1549	682	340	68	476	172	264	10400	31860	6939
171	6079	768	1549	682	340	68	476	172	264	10400	31860	6939
172	6079	768	1549	682	340	68	476	172	264	10400	31860	6939
173	6079	768	1549	682	340	68	476	172	264	10400	31860	6939
174	6079	768	1549	682	340	68	476	172	264	10400	31860	6939
175	6079	768	1549	682	340	68	476	172	264	10400	31860	6939

176	6079	768	1549	682	340	68	476	172	264	10400	31860	6939
177	6080	768	1549	682	340	68	476	172	264	10400	31860	6939
178	6080	768	1549	682	340	68	476	172	264	10400	31860	6939
179	6080	768	1549	682	340	68	476	172	264	10400	31860	6939
180	6080	768	1549	682	340	68	476	172	264	10400	31860	6939
181	6080	767	1549	682	340	68	476	172	264	10400	31860	6939
182	6080	767	1549	682	340	68	476	172	264	10400	31860	6939
183	6080	767	1549	682	340	68	476	172	264	10400	31860	6939
184	6080	767	1549	682	340	68	476	172	264	10400	31860	6939
185	6080	767	1549	682	340	68	476	172	264	10400	31860	6939
186	6080	767	1549	682	340	68	476	172	264	10400	31860	6939
187	6080	767	1549	682	340	68	477	172	264	10400	31860	6938
188	6081	766	1549	682	340	68	477	172	264	10400	31860	6938
189	6081	766	1549	682	340	69	477	72	264	10400	31860	6938
190	6081	766	1549	682	340	69	477	172	264	10400	31860	6938
191	6081	766	1549	682	340	69	477	172	264	10400	31860	6938
192	6082	764	1549	682	341	69	478	172	264	10400	31861	6938
193	6083	764	1548	682	340	69	477	172	264	10400	31861	6937
194	6084	764	1548	682	340	69	477	172	264	10400	31860	6937
195	6084	764	1548	682	340	69	477	172	264	10400	31860	6937
196	6084	764	1548	682	340	69	477	172	264	10400	31860	6937
197	6084	764	1548	682	340	69	477	172	264	10400	31860	6937

Table A.2 Run-by-Run Results of the GA for Case 2 (50% Variation Bound)

Run No	Residential	Office	Destination	Retail	Convention	Cinema	Hotel	Community Facility	School	Total Area	Person Trip	Vehicle Trip
1	5852	777	1756	595	399	80	558	150	233	10400	31880	7326
2	5853	776	1756	597	397	78	558	150	235	10400	31871	7316
3	5854	777	1752	599	396	76	559	151	237	10400	31863	7303
4	5855	775	1753	602	394	73	559	151	238	10400	31863	7296
5	5857	774	1751	604	391	72	561	151	239	10400	31862	7286
6	5858	774	1751	607	387	70	562	152	240	10400	31861	7274
7	5858	773	1750	608	385	69	562	152	242	10400	31862	7269
8	5859	774	1748	609	384	69	563	153	242	10400	31864	7264
9	5861	771	1746	613	381	67	563	153	245	10400	31869	7252
10	5863	770	1744	614	380	66	564	154	246	10400	31860	7245
11	5863	769	1745	616	377	65	563	155	246	10400	31871	7241
12	5864	769	1744	617	375	65	564	156	247	10400	31861	7233
13	5864	769	1744	617	375	64	564	156	248	10400	31861	7231
14	5865	768	1743	619	374	63	564	156	249	10400	31866	7226
15	5866	767	1741	622	372	60	563	158	250	10400	31867	7215
16	5866	767	1741	622	371	60	563	159	251	10400	31860	7212
17	5866	766	1740	623	371	60	564	160	251	10400	31871	7209
18	5867	765	1738	626	365	57	566	161	254	10400	31860	7192
19	5868	765	1738	627	364	56	565	161	254	10400	31862	7189
20	5869	765	1738	628	364	56	564	161	254	10400	31860	7187
21	6546	430	1352	846	365	53	514	87	208	10400	32628	6483
22	6551	427	1352	846	363	51	513	86	210	10400	32594	6472
23	6553	427	1350	847	359	47	515	89	212	10400	32537	6451
24	6555	428	1347	848	355	41	517	92	215	10400	32457	6424
25	6558	428	1344	846	351	40	521	93	219	10400	32377	6407
26	6564	425	1340	845	343	40	522	96	225	10400	32310	6384
27	6569	421	1335	843	338	40	524	100	230	10400	32229	6361
28	6569	422	1332	841	337	40	525	102	232	10400	32184	6354
29	6574	419	1330	838	333	40	526	105	235	10400	32108	6339
30	6576	416	1329	834	332	40	529	108	237	10400	32042	6330
31	6577	416	1329	833	328	40	530	109	238	10400	32003	6321
32	6579	415	1324	834	325	40	531	114	238	10400	31989	6310
33	6581	412	1324	832	320	40	533	115	242	10400	31946	6297
34	6585	412	1321	831	315	40	535	118	243	10400	31889	6282
35	6588	411	1319	831	312	40	536	119	244	10400	31860	6272
36	6588	410	1319	832	309	40	536	120	246	10400	31867	6268
37	6589	410	1317	832	307	41	537	122	246	10400	31861	6263
38	6590	409	1317	833	306	40	536	122	247	10400	31860	6261
39	6590	408	1317	834	305	40	536	122	249	10400	31866	6257
40	6591	407	1316	834	303	40	536	123	251	10400	31860	6253
41	6591	406	1316	834	303	40	535	124	251	10400	31860	6251
42	6591	406	1317	834	301	40	536	124	251	10400	31860	6250
43	6593	404	1317	835	298	40	534	124	255	10400	31861	6245
44	6593	403	1316	836	297	40	534	125	255	10400	31861	6241
45	6593	402	1316	838	295	40	533	126	257	10400	31882	6238
46	6595	403	1311	839	291	40	536	126	259	10400	31860	6226
47	6596	403	1311	840	286	40	536	128	260	10400	31861	6220
48	6597	403	1312	840	285	40	535	128	261	10400	31860	6218
49	6598	404	1311	841	283	40	535	128	261	10400	31861	6215
50	6599	403	1310	842	282	40	536	128	261	10400	31863	6212
51	6599	401	1309	843	280	40	536	130	262	10400	31860	6206
52	6600	401	1308	844	277	40	536	131	264	10400	31861	6201
53	6600	399	1307	844	276	40	536	132	266	10400	31861	6197
54	6600	400	1307	845	274	40	536	132	266	10400	31861	6194
55	6603	396	1306	846	272	40	537	133	268	10400	31862	6186
56	6604	395	1305	847	268	40	538	133	269	10400	31862	6181
57	6605	394	1304	848	266	40	538	134	271	10400	31860	6175
58	6605	394	1305	848	265	40	538	134	271	10400	31860	6174
59	6607	393	1304	849	265	40	537	133	273	10400	31860	6172
60	6607	393	1303	850	263	40	536	134	274	10400	31867	6168
61	6609	393	1302	851	260	40	537	135	275	10400	31871	6162
62	6609	391	1302	851	258	40	538	135	276	10400	31860	6157
63	6610	390	1300	853	257	40	539	135	276	10400	31868	6155
64	6610	390	1300	853	255	40	539	135	277	10400	31860	6151
65	6613	390	1296	856	251	40	538	137	279	10400	31871	6141
66	6615	390	1294	857	248	40	540	137	279	10400	31865	6134
67	6617	391	1291	858	247	40	539	137	280	10400	31865	6130
68	6617	390	1290	859	243	40	539	138	283	10400	31862	6121
69	6618	390	1287	861	241	40	539	139	284	10400	31874	6116
70	6619	390	1285	862	239	40	541	140	285	10400	31860	6109
71	6620	390	1285	862	237	40	540	140	285	10400	31860	6108
72	6620	390	1285	862	237	40	540	140	285	10400	31865	6107
73	6621	390	1283	863	237	40	540	141	285	10400	31868	6105
74	6622	390	1283	864	233	40	540	141	286	10400	31861	6099
75	6623	390	1283	864	233	40	539	141	287	10400	31860	6098
76	6623	390	1283	864	231	40	540	141	287	10400	31860	6096
77	6625	390	1283	866	229	40	541	140	287	10400	31864	6092
78	6626	391	1281	867	225	40	541	141	288	10400	31860	6086
79	6627	390	1282	868	223	40	541	141	288	10400	31871	6083
80	6627	390	1281	868	223	40	542	141	289	10400	31860	6082
81	6628	390	1281	868	222	40	541	141	289	10400	31862	6080
82	6629	390	1280	868	222	40	540	141	290	10400	31860	6079
83	6630	390	1279	870	220	40	540	141	290	10400	31872	6075
84	6631	390	1278	870	219	40	542	142	290	10400	31860	6071
85	6632	390	1276	872	213	40	541	143	293	10400	31862	6062
86	6634	391	1273	874	209	40	543	142	295	10400	31862	6053
87	6635	390	1272	875	207	40	542	142	296	10400	31866	6049
88	6638	390	1271	876	204	40	540	144	297	10400	31861	6042
89	6642	390	1270	877	202	40	539	141	299	10400	31860	6038
90	6642	390	1269	877	202	40	539	141	299	10400	31863	6037
91	6643	390	1269	877	201	40	539	142	300	10400	31861	6035
92	6643	390	1269	878	201	40	539	142	300	10400	31860	6034
93	6643	390	1268	878	200	40	538	142	301	10400	31863	6033
94	6644	390	1268	878	200	40	536	142	302	10400	31860	6031

95	6645	391	1264	879	200	40	537	142	303	10400	31860	6028
96	6645	390	1264	879	200	40	537	143	303	10400	31861	6027
97	6645	390	1263	879	200	40	534	143	306	10400	31862	6025
98	6645	390	1260	880	200	40	535	143	307	10400	31861	6022
99	6645	390	1257	881	200	40	533	144	310	10400	31860	6018
100	6646	390	1257	881	200	40	533	144	310	10400	31860	6017
101	6645	390	1257	881	200	40	533	144	310	10400	31860	6017
102	6646	390	1255	881	200	40	532	145	311	10400	31867	6015
103	6647	390	1253	881	200	40	532	145	311	10400	31860	6013
104	6647	390	1253	881	200	40	530	145	314	10400	31860	6012
105	6648	390	1252	882	200	40	529	145	314	10400	31860	6011
106	6648	390	1252	882	200	40	529	145	314	10400	31860	6011
107	6648	390	1251	882	200	40	527	145	316	10400	31872	6010
108	6649	390	1250	882	200	40	527	145	317	10400	31860	6008
109	6649	390	1250	882	200	40	526	145	317	10400	31860	6007
110	6649	390	1249	882	200	40	526	145	318	10400	31860	6007
111	6651	390	1247	883	200	40	525	146	318	10400	31860	6004
112	6652	390	1247	883	200	40	523	146	319	10400	31861	6004
113	6654	390	1246	883	200	40	521	146	320	10400	31863	6003
114	6656	390	1245	884	200	40	519	146	321	10400	31872	6001
115	6656	390	1243	883	200	40	518	147	323	10400	31862	5998
116	6657	390	1241	884	200	40	518	147	323	10400	31861	5995
117	6658	390	1239	885	200	40	518	147	323	10400	31868	5994
118	6658	390	1239	885	200	40	518	147	323	10400	31867	5993
119	6658	390	1236	886	200	40	519	147	325	10400	31860	5989
120	6659	390	1235	886	200	40	516	148	326	10400	31860	5988
121	6660	390	1233	887	200	40	515	148	328	10400	31866	5985
122	6660	390	1231	887	200	40	514	148	330	10400	31862	5983
123	6660	390	1231	887	200	40	514	148	330	10400	31860	5982
124	6661	390	1229	888	200	40	514	148	330	10400	31866	5980
125	6662	390	1228	888	200	40	515	147	330	10400	31864	5978
126	6664	390	1224	889	200	40	514	148	331	10400	31861	5973
127	6664	390	1222	889	200	40	514	148	332	10400	31860	5971
128	6664	390	1222	889	200	40	514	148	332	10400	31860	5971
129	6664	390	1222	889	200	40	514	148	332	10400	31860	5971
130	6665	390	1222	889	200	40	514	148	332	10400	31860	5970
131	6666	390	1222	889	200	40	513	148	332	10400	31860	5970
132	6666	390	1221	889	200	40	512	148	333	10400	31861	5970
133	6667	390	1220	889	200	40	510	148	335	10400	31860	5968
134	6669	390	1220	889	200	40	508	148	335	10400	31861	5968
135	6669	390	1220	889	200	40	505	148	339	10400	31860	5966
136	6669	390	1220	889	200	40	505	148	339	10400	31860	5966
137	6669	390	1220	889	200	40	505	148	339	10400	31860	5966
138	6669	390	1220	889	200	40	505	148	339	10400	31860	5966
139	6669	390	1219	889	200	40	504	149	340	10400	31860	5965
140	6669	390	1219	889	200	40	504	149	340	10400	31860	5965
141	6670	390	1219	889	200	40	502	149	341	10400	31861	5965
142	6670	390	1219	889	200	40	502	149	341	10400	31860	5964
143	6670	390	1218	889	200	40	500	149	343	10400	31860	5963
144	6670	390	1218	889	200	40	500	149	343	10400	31860	5963
145	6670	390	1218	889	200	40	500	149	344	10400	31860	5963
146	6670	390	1217	889	200	40	499	149	345	10400	31860	5962
147	6670	390	1217	889	200	40	499	149	345	10400	31860	5962
148	6670	390	1217	889	200	40	499	149	345	10400	31860	5962
149	6671	390	1217	889	200	40	498	149	345	10400	31860	5962
150	6673	390	1217	889	200	40	496	149	345	10400	31860	5962
151	6674	390	1217	889	200	40	495	149	345	10400	31860	5962
152	6675	390	1217	889	200	40	494	149	345	10400	31860	5962
153	6675	390	1217	889	200	40	494	149	345	10400	31860	5961
154	6676	390	1217	889	200	40	493	149	345	10400	31860	5961
155	6676	390	1217	889	200	40	493	149	345	10400	31860	5961
156	6677	390	1217	889	200	40	492	149	345	10400	31860	5961
157	6678	390	1217	889	200	40	491	150	345	10400	31860	5961
158	6679	390	1217	889	200	40	490	150	345	10400	31860	5961
159	6679	390	1216	889	200	40	490	150	345	10400	31860	5960
160	6680	390	1216	889	200	40	489	150	345	10400	31860	5960
161	6680	390	1216	889	200	40	489	150	345	10400	31860	5960
162	6681	390	1216	889	200	40	488	150	345	10400	31860	5960
163	6681	390	1216	889	200	40	488	150	345	10400	31860	5960
164	6681	390	1216	889	200	40	488	150	345	10400	31860	5960
165	6681	390	1216	889	200	40	488	150	345	10400	31860	5960
166	6683	390	1216	889	200	40	487	150	345	10400	31860	5960
167	6683	390	1216	889	200	40	486	150	345	10400	31860	5960
168	6684	390	1216	889	200	40	485	150	345	10400	31860	5960
169	6684	390	1216	889	200	40	485	150	345	10400	31860	5960
170	6684	390	1216	889	200	40	484	151	345	10400	31861	5959
171	6684	390	1216	889	200	40	485	151	345	10400	31860	5959
172	6685	390	1216	889	200	40	483	151	345	10400	31860	5959
173	6685	390	1215	889	200	40	483	152	345	10400	31860	5958
174	6686	390	1215	889	200	40	482	152	345	10400	31860	5958
175	6686	390	1215	889	200	40	482	152	345	10400	31860	5958
176	6688	390	1215	889	200	40	480	152	345	10400	31860	5958
177	6688	390	1215	889	200	40	480	152	345	10400	31860	5957
178	6688	390	1215	889	200	40	480	152	345	10400	31860	5957
179	6688	390	1215	889	200	40	480	152	345	10400	31860	5957
180	6688	390	1215	889	200	40	480	152	345	10400	31860	5957
181	6688	390	1215	889	200	40	480	152	345	10400	31860	5957
182	6688	390	1215	889	200	40	480	152	345	10400	31860	5957

Table A.3 Run-by-Run Results of the GA for the 5% Variation Bound

Run No	Residential	Office	Destination	Retail	Convention	Cinema	Hotel	Community Facility	School	Total Area	Person Trip	Vehicle Trip
1	5844	763	1788	610	394	80	554	145	222	10400	32211	7368
2	5846	763	1786	608	394	76	555	147	225	10400	32134	7352
3	5936	754	1721	616	380	76	534	155	228	10400	31861	7223
4	5939	750	1718	617	380	76	533	157	230	10400	31867	7217
5	5939	750	1717	617	380	76	534	157	230	10400	31860	7215
6	5939	749	1717	617	380	76	534	157	231	10400	31860	7214
7	5940	749	1716	617	380	76	534	157	231	10400	31860	7213
8	5940	749	1716	617	380	76	534	157	231	10400	31860	7213
9	5939	748	1716	617	380	76	533	157	233	10400	31860	7212
10	5940	746	1715	618	380	76	533	157	235	10400	31860	7210
11	5940	746	1714	618	380	76	533	157	235	10400	31860	7207
12	5941	744	1712	619	380	76	534	157	236	10400	31867	7205
13	5944	743	1712	619	380	76	534	156	236	10400	31861	7203
14	5944	743	1711	619	380	76	533	157	237	10400	31860	7202
15	5945	742	1710	619	380	76	533	157	238	10400	31860	7200
16	5945	742	1709	620	380	76	534	156	238	10400	31866	7198
17	5945	741	1705	621	380	76	535	156	240	10400	31863	7193
18	5946	741	1702	622	380	76	536	157	240	10400	31866	7189
19	5949	741	1700	622	380	76	534	157	241	10400	31860	7187
20	5949	741	1700	622	380	76	533	157	241	10400	31860	7186
21	5950	741	1700	623	380	76	533	157	241	10400	31860	7186
22	5950	741	1700	623	380	76	533	157	241	10400	31860	7186
23	5950	741	1700	623	380	76	533	157	241	10400	31860	7186
24	5950	741	1700	623	380	76	533	157	241	10400	31860	7185
25	5950	741	1699	623	380	76	533	157	241	10400	31860	7185
26	5950	741	1699	623	380	76	533	157	241	10400	31860	7185
27	5950	741	1699	623	380	76	533	157	241	10400	31860	7185
28	5950	741	1699	623	380	76	532	157	241	10400	31860	7185
29	5950	741	1699	623	380	76	532	157	241	10400	31860	7185
30	5950	741	1699	623	380	76	532	157	241	10400	31860	7185
31	5950	741	1699	623	380	76	532	157	241	10400	31860	7185
32	5950	741	1699	623	380	76	532	157	241	10400	31860	7185
33	5950	741	1699	623	380	76	532	157	241	10400	31860	7185
34	5950	741	1699	623	380	76	532	157	241	10400	31860	7185
35	5950	741	1699	623	380	76	532	157	241	10400	31860	7185
36	5950	741	1699	623	380	76	532	157	241	10400	31860	7185
37	5950	741	1699	623	380	76	532	157	241	10400	31860	7185
38	5950	741	1699	623	380	76	532	157	241	10400	31860	7185
39	5950	741	1699	623	380	76	532	157	241	10400	31861	7185
40	5950	741	1699	623	380	76	532	157	241	10400	31860	7185
41	5950	741	1699	623	380	76	532	157	241	10400	31860	7185
42	5950	741	1699	623	380	76	532	157	241	10400	31860	7185
43	5950	741	1699	623	380	76	532	157	241	10400	31860	7185
44	5950	741	1699	623	380	76	532	157	241	10400	31860	7185
45	5950	741	1699	623	380	76	532	157	241	10400	31860	7185
46	5950	741	1699	623	380	76	532	157	241	10400	31860	7185
47	5950	741	1699	623	380	76	532	157	241	10400	31860	7185
48	5950	741	1699	623	380	76	532	157	241	10400	31860	7185
49	5950	741	1699	623	380	76	532	157	241	10400	31860	7185
50	5950	741	1699	623	380	76	532	157	241	10400	31860	7185
51	5951	741	1698	623	380	76	532	157	241	10400	31860	7185
52	5951	741	1698	623	380	76	532	157	241	10400	31860	7185
53	5951	741	1698	623	380	76	532	157	241	10400	31860	7185
54	5951	741	1698	623	380	76	532	157	241	10400	31860	7185
55	5951	741	1698	623	380	76	532	157	241	10400	31860	7185
56	5951	741	1698	623	380	76	532	157	241	10400	31860	7185
57	5951	741	1698	623	380	76	532	157	241	10400	31860	7185
58	5951	741	1698	623	380	76	532	157	241	10400	31860	7185
59	5951	741	1698	623	380	76	532	157	241	10400	31860	7185
60	5951	741	1698	623	380	76	532	157	241	10400	31860	7185
61	5951	741	1698	623	380	76	532	157	242	10400	31860	7185
62	5951	741	1697	623	380	77	533	157	241	10400	31860	7184
63	5951	741	1697	623	380	77	533	157	241	10400	31860	7184
64	5951	741	1697	623	380	77	533	157	241	10400	31860	7184
65	5951	741	1697	623	380	77	533	157	241	10400	31860	7184

Table A.4 Run-by-Run Results of the GA for the 10% Variation Bound

Run No	Residential	Office	Destination	Retail	Convention	Cinema	Hotel	Community Facility	School	Total Area	Person Trip	Vehicle Trip
1	5852	746	1757	641	396	79	549	150	230	10400	32528	7336
2	5855	746	1756	640	392	73	552	152	235	10400	32417	7308
3	5858	746	1753	637	388	72	554	154	239	10400	32337	7291
4	5859	743	1752	632	385	72	558	156	243	10400	32250	7278
5	5867	741	1744	630	379	72	560	158	248	10400	32158	7253
6	5868	741	1743	629	378	72	560	160	249	10400	32133	7248
7	5868	742	1739	628	374	72	562	164	251	10400	32085	7235
8	5874	741	1733	625	371	72	566	164	253	10400	31995	7217
9	5875	743	1732	622	370	72	569	165	253	10400	31938	7212
10	5877	744	1730	620	367	72	571	165	253	10400	31889	7204
11	5881	743	1730	620	362	72	573	165	253	10400	31860	7195
12	5882	743	1730	620	362	72	573	165	253	10400	31860	7194
13	5882	743	1730	621	361	72	573	165	253	10400	31863	7193
14	5884	742	1730	621	360	72	574	165	253	10400	31860	7190
15	5884	742	1728	622	360	72	574	165	253	10400	31865	7188
16	5886	742	1728	622	360	72	573	165	253	10400	31861	7188
17	5886	742	1727	623	360	72	573	165	253	10400	31871	7187
18	5887	743	1725	623	360	72	573	165	253	10400	31860	7184
19	5887	743	1725	623	360	72	573	165	253	10400	31860	7184
20	5888	743	1723	623	360	72	573	165	252	10400	31861	7183
21	5889	743	1723	624	360	72	573	165	252	10400	31860	7182
22	5889	743	1722	624	360	72	573	165	253	10400	31860	7181
23	5889	742	1720	624	360	72	574	165	253	10400	31861	7179
24	5891	742	1719	625	360	72	573	165	253	10400	31860	7177
25	5895	741	1717	625	360	72	571	165	253	10400	31862	7174
26	5896	741	1717	625	360	72	571	165	253	10400	31860	7173
27	5897	740	1716	626	360	72	570	165	253	10400	31871	7172
28	5899	739	1713	627	360	72	572	165	253	10400	31867	7167
29	5901	739	1712	627	360	72	571	165	253	10400	31860	7165
30	5901	738	1712	627	360	72	571	165	253	10400	31861	7165
31	5902	738	1710	628	360	72	572	165	253	10400	31860	7162
32	5902	738	1710	628	360	72	572	165	253	10400	31860	7162
33	5904	738	1707	629	360	72	572	165	253	10400	31866	7159
34	5904	737	1707	629	360	72	573	165	253	10400	31861	7157
35	5907	736	1704	630	360	72	573	165	253	10400	31860	7153
36	5908	735	1703	630	360	72	574	165	253	10400	31862	7152
37	5910	732	1700	633	360	72	575	165	253	10400	31882	7146
38	5912	730	1697	633	360	72	577	165	253	10400	31860	7141
39	5914	730	1697	633	360	72	576	165	253	10400	31860	7140
40	5916	730	1697	633	360	72	574	165	253	10400	31860	7140
41	5920	729	1697	633	360	72	572	165	253	10400	31860	7138
42	5920	729	1695	634	360	72	572	165	253	10400	31871	7137
43	5920	729	1694	634	360	72	573	165	253	10400	31860	7135
44	5923	727	1692	635	360	72	574	164	253	10400	31860	7131
45	5924	727	1690	636	360	72	574	164	253	10400	31865	7129
46	5926	727	1688	637	360	72	574	163	253	10400	31865	7126
47	5929	724	1686	637	360	72	574	165	253	10400	31861	7122
48	5929	724	1685	638	360	72	574	165	253	10400	31871	7121
49	5931	723	1683	638	360	72	575	165	253	10400	31860	7117
50	5931	723	1682	638	360	72	575	165	253	10400	31861	7116
51	5933	723	1679	639	360	72	576	164	253	10400	31860	7112
52	5933	723	1678	640	360	72	576	165	253	10400	31860	7111
53	5933	723	1678	640	360	72	576	165	253	10400	31860	7111
54	5934	721	1678	640	360	72	577	164	253	10400	31864	7110
55	5935	720	1676	641	360	72	578	165	253	10400	31861	7107
56	5937	720	1676	641	360	72	576	165	253	10400	31860	7106
57	5937	720	1676	641	360	72	576	165	253	10400	31860	7105
58	5938	720	1675	641	360	72	577	165	253	10400	31860	7104
59	5939	720	1674	641	360	72	576	165	253	10400	31862	7104
60	5939	720	1674	641	360	72	576	165	253	10400	31860	7103
61	5940	720	1673	642	360	72	576	165	253	10400	31862	7102
62	5940	720	1672	642	360	72	576	165	253	10400	31860	7101
63	5941	719	1670	643	360	72	577	165	253	10400	31861	7098
64	5941	719	1670	643	360	72	577	165	253	10400	31861	7098
65	5941	719	1669	643	360	72	577	165	253	10400	31860	7097
66	5942	718	1669	643	360	72	578	165	253	10400	31860	7096
67	5942	718	1669	643	360	72	578	165	253	10400	31860	7096
68	5944	717	1669	643	360	72	576	165	253	10400	31861	7096
69	5946	717	1667	644	360	72	575	165	253	10400	31860	7092
70	5947	717	1666	644	360	72	576	165	253	10400	31860	7091
71	5950	716	1665	645	360	72	574	164	253	10400	31863	7090
72	5951	715	1665	645	360	72	575	164	253	10400	31861	7088
73	5952	715	1664	645	360	72	574	165	253	10400	31860	7086
74	5952	714	1664	645	360	72	574	165	253	10400	31860	7086
75	5955	712	1662	647	360	72	574	165	253	10400	31878	7083
76	5958	712	1660	647	360	72	574	165	253	10400	31860	7079
77	5959	711	1659	647	360	72	573	165	253	10400	31866	7078
78	5960	710	1656	648	360	72	575	165	253	10400	31863	7074
79	5961	711	1655	648	360	72	575	165	253	10400	31860	7072
80	5963	709	1653	649	360	72	576	165	253	10400	31861	7068
81	5964	708	1652	650	360	72	576	165	253	10400	31863	7067
82	5964	708	1652	650	360	72	576	165	253	10400	31860	7066
83	5965	708	1652	650	360	72	575	165	253	10400	31860	7066
84	5967	708	1651	650	360	72	575	164	253	10400	31864	7065
85	5967	708	1649	650	360	72	575	165	253	10400	31860	7063
86	5968	707	1648	651	360	72	576	165	253	10400	31861	7060
87	5970	707	1648	651	360	72	575	165	253	10400	31860	7060
88	5970	706	1648	651	360	72	575	165	253	10400	31860	7060
89	5971	707	1645	652	360	72	576	165	253	10400	31860	7056
90	5971	707	1644	652	360	72	576	165	253	10400	31860	7056
91	5971	706	1644	652	360	72	576	165	253	10400	31860	7055
92	5973	705	1642	652	360	73	576	165	253	10400	31861	7054
93	5977	705	1642	652	360	73	573	165	253	10400	31860	7053
94	5978	705	1642	652	360	73	572	165	253	10400	31860	7053

95	5980	705	1642	652	360	73	570	165	253	10400	31860	7053
96	5980	705	1642	652	360	73	570	165	253	10400	31860	7053
97	5981	705	1642	652	360	73	569	165	253	10400	31860	7052
98	5982	705	1642	652	360	73	568	165	253	10400	31860	7052
99	5982	704	1642	652	360	73	568	165	253	10400	31860	7052
100	5982	704	1642	652	360	73	568	165	253	10400	31860	7052
101	5984	704	1642	652	360	73	566	165	253	10400	31861	7052
102	5986	704	1642	652	360	73	565	165	253	10400	31860	7052
103	5986	704	1642	652	360	73	565	165	253	10400	31860	7052
104	5987	704	1642	652	360	73	564	165	253	10400	31860	7051
105	5987	704	1642	652	360	73	564	165	253	10400	31860	7051
106	5987	704	1642	652	360	73	564	165	253	10400	31860	7051
107	5987	704	1642	652	360	73	564	165	253	10400	31860	7051
108	5987	704	1642	652	360	73	564	165	253	10400	31860	7051
109	5987	704	1642	652	360	73	564	165	253	10400	31860	7051
110	5988	704	1642	652	360	73	563	165	253	10400	31860	7051
111	5988	704	1642	652	360	73	563	165	253	10400	31860	7051
112	5988	704	1642	652	360	73	563	165	253	10400	31860	7051
113	5989	703	1642	652	360	73	562	165	253	10400	31860	7051
114	5989	703	1642	652	360	73	562	165	253	10400	31860	7051
115	5990	703	1642	652	360	73	562	165	253	10400	31860	7051
116	5990	703	1642	652	360	73	562	165	253	10400	31860	7050
117	5990	703	1642	652	360	73	562	165	253	10400	31860	7050
118	5990	703	1642	652	360	73	562	165	253	10400	31860	7050
119	5991	703	1642	652	360	73	561	165	253	10400	31860	7050
120	5992	703	1642	652	360	73	561	165	253	10400	31860	7050
121	5992	703	1642	652	360	73	561	165	253	10400	31860	7050
122	5992	703	1642	652	360	73	561	165	253	10400	31860	7050
123	5994	703	1641	652	360	73	559	165	253	10400	31861	7050
124	5995	702	1641	652	360	73	558	165	253	10400	31860	7049
125	5995	702	1641	652	360	73	558	165	253	10400	31860	7049
126	5995	702	1641	652	360	73	558	165	253	10400	31860	7049
127	5997	702	1641	652	360	73	556	165	253	10400	31860	7049
128	5997	702	1641	652	360	73	556	165	253	10400	31860	7049
129	6000	702	1641	652	360	73	553	165	253	10400	31860	7048
130	6001	702	1641	652	360	73	552	165	253	10400	31860	7048
131	6003	702	1641	652	360	73	551	165	253	10400	31860	7048
132	6004	702	1641	652	360	73	550	165	253	10400	31860	7048
133	6004	702	1641	652	360	73	550	165	253	10400	31860	7048
134	6005	702	1641	652	360	73	549	165	253	10400	31860	7048
135	6005	702	1641	652	360	73	549	165	253	10400	31860	7048
136	6005	702	1641	652	360	73	549	165	253	10400	31860	7048
137	6005	702	1641	652	360	73	549	165	253	10400	31860	7048
138	6006	702	1641	652	360	73	548	165	253	10400	31860	7047
139	6007	702	1641	652	360	73	547	165	253	10400	31860	7047
140	6007	702	1641	652	360	73	547	165	253	10400	31860	7047
141	6009	702	1641	652	360	73	545	165	253	10400	31860	7047
142	6009	702	1641	652	360	73	545	165	253	10400	31860	7047
143	6013	702	1641	652	360	73	541	165	253	10400	31860	7046
144	6014	702	1641	652	360	73	540	165	253	10400	31860	7046
145	6014	702	1641	652	360	73	540	165	253	10400	31860	7046
146	6014	702	1641	652	360	73	540	165	253	10400	31860	7046
147	6014	702	1641	652	360	73	540	165	253	10400	31860	7046
148	6014	702	1640	652	360	73	540	165	253	10400	31860	7046
149	6014	702	1640	652	360	73	540	165	253	10400	31860	7046
150	6016	702	1640	652	360	73	538	165	253	10400	31860	7046
151	6016	702	1640	652	360	73	538	165	253	10400	31860	7046
152	6017	702	1640	652	360	73	537	165	253	10400	31860	7046
153	6017	702	1640	652	360	73	537	165	253	10400	31860	7046

Table A.5 Run-by-Run Results of the GA for the 20% Variation Bound

Run No	Residential	Office	Destination	Retail	Convention	Cinema	Hotel	Community Facility	School	Total Area	Person Trip	Vehicle Trip
1	5850	780	1755	595	399	80	560	151	231	10400	31876	7326
2	5851	780	1754	596	397	79	561	152	231	10400	31864	7318
3	5851	780	1754	598	394	77	561	152	233	10400	31862	7309
4	5851	779	1753	600	391	76	563	154	233	10400	31861	7303
5	5852	776	1752	602	390	75	563	155	235	10400	31868	7295
6	5853	776	1752	602	388	75	563	156	236	10400	31860	7290
7	5853	775	1752	602	387	75	564	156	236	10400	31860	7288
8	5855	775	1750	605	386	73	564	157	235	10400	31872	7282
9	5856	775	1746	608	384	71	566	158	237	10400	31860	7267
10	5858	766	1640	710	391	66	570	160	239	10400	32913	7198
11	5861	765	1638	710	389	64	570	161	243	10400	32866	7183
12	5862	766	1632	710	388	64	572	162	245	10400	32838	7173
13	5865	766	1629	709	384	64	572	164	247	10400	32792	7162
14	5869	766	1626	709	380	64	574	163	248	10400	32765	7150
15	5874	763	1621	706	375	64	578	167	252	10400	32672	7129
16	5877	763	1614	701	372	64	581	173	255	10400	32556	7108
17	5881	761	1610	698	367	64	585	174	260	10400	32461	7089
18	5885	760	1609	693	365	64	587	175	262	10400	32374	7077
19	5888	762	1604	694	361	64	587	176	264	10400	32352	7066
20	5893	760	1601	690	357	64	588	179	267	10400	32260	7048
21	5897	760	1597	685	352	64	592	180	274	10400	32140	7028
22	5900	760	1594	685	346	64	595	180	276	10400	32095	7013
23	5901	760	1593	685	345	64	596	180	276	10400	32086	7011
24	5902	761	1592	684	344	64	597	180	276	10400	32065	7007
25	5909	761	1589	683	340	64	598	180	276	10400	32008	6995
26	5912	761	1586	684	337	64	601	180	276	10400	31992	6985
27	5916	758	1582	683	333	64	609	179	276	10400	31927	6971
28	5919	757	1582	683	326	64	614	179	276	10400	31886	6956
29	5922	757	1580	682	325	64	614	180	275	10400	31860	6951
30	5922	757	1579	682	325	64	614	180	276	10400	31862	6950
31	5923	757	1579	683	325	64	614	180	276	10400	31860	6949
32	5925	757	1578	683	323	64	614	180	276	10400	31860	6946
33	5926	755	1575	686	321	64	616	180	276	10400	31869	6940
34	5929	753	1573	686	320	64	618	180	276	10400	31860	6933
35	5932	753	1571	687	320	64	617	180	276	10400	31860	6931
36	5932	753	1571	687	320	64	617	180	276	10400	31860	6930
37	5932	753	1571	687	320	64	617	180	276	10400	31860	6930
38	5935	751	1569	688	320	64	617	180	276	10400	31866	6927
39	5938	751	1567	688	320	64	616	180	276	10400	31861	6924
40	5941	749	1566	689	320	64	616	179	275	10400	31866	6922
41	5945	749	1564	690	320	64	614	179	276	10400	31860	6918
42	5946	747	1562	691	320	64	615	180	275	10400	31865	6915
43	5947	746	1560	692	320	64	616	180	276	10400	31871	6912
44	5947	746	1558	692	320	64	617	180	276	10400	31860	6909
45	5949	746	1558	692	320	64	616	180	276	10400	31860	6908
46	5949	745	1557	692	320	64	616	180	276	10400	31860	6907
47	5950	744	1557	692	320	64	616	180	276	10400	31862	6906
48	5950	744	1556	693	320	64	617	180	276	10400	31865	6904
49	5951	743	1555	693	320	64	617	180	276	10400	31860	6903
50	5953	743	1554	694	320	64	616	180	275	10400	31864	6902
51	5957	743	1552	695	320	64	614	180	276	10400	31873	6899
52	5959	744	1549	695	320	64	614	179	276	10400	31867	6896
53	5961	742	1547	696	320	64	614	179	276	10400	31871	6893
54	5962	741	1546	696	320	64	615	180	276	10400	31865	6890
55	5964	739	1545	697	320	64	615	180	276	10400	31860	6887
56	5964	739	1545	697	320	64	615	180	276	10400	31860	6886
57	5966	738	1542	699	320	64	615	180	276	10400	31882	6883
58	5968	738	1541	698	320	64	616	180	276	10400	31860	6881
59	5969	737	1540	699	320	64	615	180	276	10400	31871	6879
60	5970	737	1536	700	320	64	616	180	276	10400	31861	6874
61	5971	737	1536	700	320	64	616	180	276	10400	31860	6874
62	5971	737	1536	700	320	64	616	180	276	10400	31860	6874
63	5971	737	1535	700	320	64	616	180	276	10400	31862	6873
64	5973	736	1534	700	320	64	617	179	276	10400	31860	6871
65	5974	736	1534	701	320	64	616	179	276	10400	31860	6871
66	5975	735	1532	701	320	64	617	180	276	10400	31862	6868
67	5977	735	1530	702	320	64	616	180	276	10400	31862	6865
68	5979	735	1527	703	320	64	616	180	276	10400	31861	6861
69	5981	734	1526	703	320	64	616	180	276	10400	31860	6859
70	5982	734	1526	703	320	64	615	180	276	10400	31861	6858
71	5985	733	1525	703	320	64	612	180	276	10400	31860	6857
72	5987	733	1525	704	320	64	612	180	276	10400	31860	6856
73	5987	733	1524	704	320	64	612	180	276	10400	31860	6855
74	5987	733	1524	704	320	64	612	180	276	10400	31860	6855
75	5988	733	1523	704	320	64	612	180	276	10400	31861	6855
76	5988	732	1523	704	320	64	612	180	276	10400	31860	6854
77	5988	732	1523	704	320	64	613	180	276	10400	31860	6853
78	5988	732	1523	704	320	64	613	180	276	10400	31860	6853
79	5989	732	1522	705	320	64	613	180	276	10400	31860	6852
80	5989	732	1522	705	320	64	613	180	276	10400	31860	6852
81	5991	732	1522	705	320	64	611	180	276	10400	31861	6852
82	5991	732	1522	705	320	64	611	180	276	10400	31860	6852
83	5991	732	1520	705	320	64	611	180	276	10400	31862	6851
84	5992	732	1520	705	320	64	610	180	276	10400	31860	6850
85	5994	732	1520	705	320	64	608	180	276	10400	31861	6850
86	5995	732	1520	705	320	64	608	180	276	10400	31860	6849
87	5995	732	1520	705	320	64	608	180	276	10400	31860	6849
88	5995	732	1519	705	320	64	608	180	276	10400	31861	6848
89	5998	730	1518	706	320	64	608	180	276	10400	31861	6845
90	5999	730	1518	706	320	64	607	180	276	10400	31860	6845
91	5999	732	1515	707	320	64	607	180	276	10400	31866	6843
92	6000	732	1514	707	320	64	608	180	276	10400	31860	6841
93	6000	731	1513	707	320	64	608	180	276	10400	31860	6840
94	6001	731	1512	708	320	64	608	180	276	10400	31864	6839

95	6002	731	1511	708	320	64	608	180	276	10400	31861	6838
96	6003	731	1510	709	320	64	608	180	276	10400	31860	6835
97	6005	730	1510	709	320	64	607	180	276	10400	31860	6835
98	6005	730	1509	710	320	64	607	180	276	10400	31871	6834
99	6006	729	1507	710	320	64	610	179	276	10400	31860	6831
100	6008	729	1504	711	320	64	608	180	276	10400	31862	6827
101	6008	728	1504	711	320	64	608	180	276	10400	31862	6827
102	6009	728	1504	711	320	64	609	180	276	10400	31860	6826
103	6009	728	1504	711	320	64	609	180	276	10400	31860	6826
104	6009	728	1504	711	320	64	609	180	276	10400	31860	6826
105	6009	728	1503	711	320	64	608	180	276	10400	31860	6826
106	6009	728	1503	711	320	64	608	180	276	10400	31860	6825
107	6011	727	1502	711	320	64	608	180	276	10400	31861	6824
108	6011	727	1502	712	320	64	608	180	276	10400	31861	6823
109	6012	727	1501	712	320	64	608	180	276	10400	31860	6822
110	6012	727	1501	712	320	64	608	180	276	10400	31860	6822
111	6012	727	1501	712	320	64	608	180	276	10400	31860	6822
112	6012	727	1501	712	320	64	608	180	276	10400	31860	6822
113	6012	727	1501	712	320	64	608	180	276	10400	31860	6822
114	6014	726	1501	712	320	64	607	180	276	10400	31861	6822
115	6015	726	1501	712	320	64	606	180	276	10400	31860	6821
116	6015	726	1501	712	320	64	606	180	276	10400	31860	6821
117	6016	726	1501	712	320	64	605	180	276	10400	31860	6821
118	6016	726	1501	712	320	64	605	180	276	10400	31860	6821
119	6016	726	1501	712	320	64	605	180	276	10400	31860	6821
120	6018	726	1501	712	320	64	604	180	276	10400	31860	6821
121	6019	726	1501	712	320	64	603	180	276	10400	31860	6820
122	6020	725	1501	712	320	64	602	180	276	10400	31860	6820
123	6020	725	1501	712	320	64	602	180	276	10400	31860	6820

Table A.6 Run-by-Run Results of the GA for the 25% Variation Bound

Run No	Residential	Office	Destination	Retail	Convention	Cinema	Hotel	Community Facility	School	Total Area	Person Trip	Vehicle Trip
1	5851	769	1757	595	402	89	558	150	229	10400	31984	7351
2	5853	767	1755	594	399	84	563	153	232	10400	31899	7325
3	5853	768	1754	594	396	82	563	155	234	10400	31860	7314
4	5853	767	1753	596	396	82	564	155	235	10400	31869	7311
5	5854	766	1752	596	394	81	565	156	235	10400	31861	7306
6	5854	765	1752	598	392	80	565	156	238	10400	31864	7300
7	5856	765	1751	598	392	80	563	157	239	10400	31860	7296
8	5856	764	1749	600	389	80	563	158	240	10400	31871	7292
9	5858	764	1748	602	387	78	563	159	242	10400	31861	7281
10	5859	763	1748	603	386	77	563	159	242	10400	31860	7277
11	5859	761	1748	604	385	76	564	160	243	10400	31868	7274
12	5860	759	1747	605	385	75	564	163	243	10400	31861	7266
13	5861	931	1521	679	384	68	565	144	247	10400	32046	7119
14	5863	930	1519	677	383	66	566	146	249	10400	31991	7108
15	5868	929	1518	673	380	62	568	150	253	10400	31862	7083
16	5868	929	1517	674	379	62	568	150	254	10400	31860	7078
17	5868	928	1517	674	379	61	569	150	254	10400	31860	7077
18	5870	926	1515	676	378	60	569	151	255	10400	31860	7070
19	5871	926	1515	676	378	60	568	151	255	10400	31860	7068
20	5873	926	1514	677	376	60	566	151	257	10400	31872	7066
21	5873	925	1514	678	374	60	566	153	258	10400	31871	7062
22	5875	923	1511	678	374	60	566	154	259	10400	31860	7056
23	5875	921	1512	678	371	61	566	156	259	10400	31860	7053
24	5877	921	1509	680	370	60	568	157	259	10400	31864	7046
25	5878	921	1506	683	365	60	567	158	263	10400	31872	7035
26	5879	920	1505	683	363	60	568	158	264	10400	31860	7030
27	5880	919	1506	683	362	60	566	159	265	10400	31861	7029
28	5880	919	1506	684	361	60	566	159	265	10400	31866	7028
29	5880	918	1504	685	360	60	567	159	266	10400	31871	7024
30	5882	916	1502	685	359	60	567	161	267	10400	31860	7017
31	5882	916	1501	686	358	60	568	161	268	10400	31860	7015
32	5883	913	1500	687	357	60	568	164	269	10400	31867	7010
33	5885	912	1498	687	357	60	567	164	270	10400	31862	7006
34	5886	910	1497	688	355	60	568	165	271	10400	31861	7000
35	5888	911	1494	690	352	60	568	165	273	10400	31860	6993
36	5888	911	1494	690	351	60	568	166	273	10400	31860	6992
37	5888	909	1495	691	348	60	568	166	274	10400	31871	6987
38	5889	908	1494	691	346	60	569	167	275	10400	31861	6983
39	5890	908	1494	693	342	60	571	167	275	10400	31869	6977
40	5891	906	1491	695	338	60	572	170	278	10400	31860	6965
41	5892	906	1490	695	337	60	572	171	278	10400	31861	6963
42	5892	904	1489	696	335	60	572	173	278	10400	31865	6958
43	5893	904	1488	697	334	60	572	173	279	10400	31862	6954
44	5894	900	1487	698	332	60	572	175	283	10400	31863	6946
45	5895	899	1484	699	329	60	573	176	284	10400	31861	6938
46	5897	897	1482	701	326	60	573	179	285	10400	31869	6930
47	5897	896	1481	701	325	60	572	180	287	10400	31860	6927
48	5900	896	1477	703	324	60	572	181	287	10400	31864	6920
49	5901	892	1474	704	322	60	573	185	287	10400	31866	6911
50	5902	891	1474	705	320	60	574	187	287	10400	31864	6906
51	5903	892	1472	706	317	60	574	187	287	10400	31861	6901
52	5904	892	1471	708	314	60	576	187	287	10400	31865	6895
53	5907	892	1469	709	312	60	577	187	287	10400	31860	6890
54	5908	892	1469	709	312	60	576	187	287	10400	31860	6889
55	5909	892	1467	709	312	60	576	187	287	10400	31860	6887
56	5911	891	1466	711	309	60	578	187	287	10400	31863	6881
57	5913	891	1465	712	307	60	578	187	287	10400	31862	6878
58	5913	891	1465	712	305	60	578	187	287	10400	31861	6875
59	5916	891	1465	713	302	60	578	187	288	10400	31862	6871
60	5917	891	1464	713	302	60	578	187	287	10400	31860	6869
61	5919	891	1464	714	301	60	577	187	287	10400	31860	6868
62	5921	891	1463	714	300	60	577	187	287	10400	31860	6865
63	5921	890	1462	715	300	60	577	187	287	10400	31860	6863
64	5922	890	1461	715	300	60	577	187	287	10400	31860	6862
65	5922	890	1461	715	300	60	577	187	287	10400	31860	6862
66	5924	888	1459	716	300	60	578	187	287	10400	31862	6859
67	5925	888	1459	716	300	60	578	187	287	10400	31860	6857
68	5925	887	1459	716	300	60	578	187	287	10400	31860	6857
69	5929	885	1455	719	300	60	580	186	287	10400	31872	6851
70	5930	885	1452	719	300	60	581	186	287	10400	31860	6847
71	5931	885	1451	719	300	60	580	187	287	10400	31860	6846
72	5932	885	1450	719	300	60	579	187	287	10400	31860	6845
73	5934	882	1447	721	300	60	581	187	287	10400	31872	6839
74	5936	881	1445	721	300	60	581	187	287	10400	31866	6836
75	5938	881	1445	721	300	60	580	187	288	10400	31860	6835
76	5938	880	1443	722	300	60	581	187	288	10400	31871	6833
77	5940	881	1442	722	300	60	581	187	287	10400	31861	6831
78	5941	880	1441	723	300	60	581	187	287	10400	31860	6829
79	5941	880	1440	723	300	60	581	187	287	10400	31862	6828
80	5942	880	1440	723	300	60	580	187	287	10400	31860	6828
81	5942	880	1440	723	300	60	580	187	287	10400	31860	6828
82	5942	880	1440	723	300	60	580	187	287	10400	31860	6827
83	5942	880	1439	723	300	60	580	187	287	10400	31860	6827
84	5943	879	1439	723	300	60	580	187	287	10400	31860	6827
85	5944	879	1437	724	300	60	580	187	288	10400	31864	6824
86	5947	879	1435	725	300	60	580	187	287	10400	31871	6821
87	5948	878	1433	725	300	60	580	187	287	10400	31864	6818
88	5949	878	1433	725	300	60	581	187	287	10400	31860	6817
89	5949	877	1433	725	300	60	581	187	287	10400	31860	6817
90	5949	877	1432	726	300	60	581	187	287	10400	31860	6816
91	5952	877	1430	727	300	60	579	187	287	10400	31873	6815
92	5953	877	1428	728	300	60	579	187	288	10400	31871	6812
93	5953	878	1427	727	300	60	579	187	287	10400	31866	6811
94	5955	879	1423	729	300	60	580	187	287	10400	31867	6806

95	5957	879	1420	730	300	60	582	186	287	10400	31861	6802
96	5958	878	1419	730	300	60	581	187	287	10400	31861	6801
97	5958	877	1416	732	300	60	581	187	287	10400	31880	6798
98	5962	878	1411	733	300	60	583	186	287	10400	31861	6790
99	5963	877	1410	733	300	60	583	187	287	10400	31860	6789
100	5963	877	1410	733	300	60	583	187	287	10400	31860	6789
101	5963	877	1410	733	300	60	583	187	287	10400	31860	6788
102	5963	877	1409	733	300	60	583	187	287	10400	31860	6788
103	5964	877	1409	733	300	60	582	187	287	10400	31861	6787
104	5965	877	1407	734	300	60	582	187	287	10400	31860	6785
105	5965	877	1407	734	300	60	582	187	287	10400	31860	6785
106	5968	873	1405	735	300	60	585	187	287	10400	31861	6780
107	5971	872	1405	735	300	60	582	187	287	10400	31861	6779
108	5973	872	1402	736	300	60	583	186	287	10400	31868	6776
109	5974	871	1401	736	300	60	583	187	287	10400	31860	6773
110	5976	870	1401	736	300	60	582	187	287	10400	31861	6772
111	5976	870	1401	737	300	60	583	187	287	10400	31860	6771
112	5976	869	1399	738	300	60	584	187	287	10400	31868	6769
113	5979	866	1399	737	300	60	584	187	287	10400	31861	6766
114	5980	866	1398	738	300	60	583	187	287	10400	31860	6765
115	5980	866	1398	738	300	60	583	187	287	10400	31860	6765
116	5981	864	1398	738	301	60	584	187	287	10400	31860	6764
117	5983	863	1398	738	300	60	583	187	287	10400	31860	6763
118	5984	863	1396	739	300	60	583	187	287	10400	31872	6761
119	5987	861	1395	739	300	60	582	187	287	10400	31860	6757
120	5988	860	1393	740	300	60	585	187	287	10400	31861	6753
121	5990	859	1391	741	300	60	584	187	287	10400	31869	6751
122	5992	855	1391	741	300	60	586	187	287	10400	31860	6748
123	5992	855	1391	741	300	60	586	187	287	10400	31860	6748
124	5993	854	1391	741	300	60	585	187	287	10400	31860	6747
125	5994	854	1391	741	300	60	585	187	287	10400	31860	6747
126	5994	854	1391	741	300	60	585	187	287	10400	31860	6746
127	5995	854	1391	741	300	60	584	187	287	10400	31860	6746
128	5995	853	1391	741	300	60	585	187	287	10400	31860	6746
129	5995	853	1391	741	300	60	585	187	287	10400	31860	6746
130	5995	853	1391	741	300	60	584	187	287	10400	31860	6746
131	5996	853	1391	741	300	60	584	187	287	10400	31860	6746
132	5996	853	1391	741	300	60	584	187	287	10400	31860	6746
133	5996	853	1391	741	300	60	584	187	287	10400	31860	6746
134	5998	853	1391	741	300	60	582	187	287	10400	31860	6745
135	5998	852	1391	741	300	60	583	187	287	10400	31860	6745
136	5999	852	1390	741	300	61	582	187	287	10400	31860	6745
137	5999	852	1390	741	300	60	582	187	287	10400	31860	6745
138	6000	852	1390	741	300	60	581	187	287	10400	31860	6745
139	6000	852	1390	741	300	61	581	187	287	10400	31860	6745
140	6001	852	1390	741	300	61	580	187	287	10400	31860	6744
141	6002	852	1390	741	300	61	580	187	287	10400	31860	6744
142	6003	852	1390	741	300	61	579	187	287	10400	31860	6744
143	6004	851	1390	741	300	61	578	187	287	10400	31860	6744
144	6006	851	1390	741	300	61	576	187	287	10400	31860	6743
145	6009	851	1389	741	300	61	574	187	287	10400	31860	6743
146	6010	851	1389	741	300	61	573	187	287	10400	31860	6743
147	6010	851	1389	741	300	61	573	187	287	10400	31860	6743
148	6010	851	1389	741	300	61	573	187	287	10400	31860	6743
149	6011	851	1389	741	300	61	572	187	287	10400	31860	6742
150	6011	851	1389	741	300	61	571	187	287	10400	31860	6742
151	6011	851	1389	741	300	61	571	187	287	10400	31860	6742
152	6012	851	1389	741	300	61	571	187	287	10400	31860	6742

Table A.7 Run-by-Run Results of the GA for the 30% Variation Bound

Run No	Residential	Office	Destination	Retail	Convention	Cinema	Hotel	Community Facility	School	Total Area	Person Trip	Vehicle Trip
1	5849	861	1632	650	437	68	559	150	195	10400	32254	7291
2	5852	862	1632	648	434	61	561	151	199	10400	32140	7265
3	5856	863	1629	646	432	56	563	154	201	10400	32031	7241
4	5859	861	1627	647	430	56	563	155	203	10400	32018	7232
5	5861	860	1625	643	427	56	566	155	207	10400	31934	7220
6	5863	860	1623	640	425	56	567	157	209	10400	31882	7211
7	5865	859	1621	640	422	56	567	158	212	10400	31861	7202
8	5865	857	1621	640	422	56	567	160	212	10400	31860	7199
9	5865	857	1621	641	420	56	567	159	213	10400	31861	7198
10	5865	857	1620	642	420	56	567	159	213	10400	31871	7197
11	5867	856	1618	643	417	56	569	160	215	10400	31861	7188
12	6089	925	1383	759	306	78	481	162	216	10400	32377	6871
13	6092	924	1382	758	304	74	484	163	217	10400	32294	6853
14	6097	924	1376	759	302	69	487	165	221	10400	32223	6826
15	6098	923	1372	758	299	65	490	168	227	10400	32127	6801
16	6105	923	1368	751	297	57	494	171	234	10400	31910	6762
17	6107	922	1366	750	295	56	497	172	234	10400	31860	6750
18	6108	921	1366	751	294	56	496	172	235	10400	31860	6748
19	6109	921	1365	752	291	56	495	173	238	10400	31862	6741
20	6110	921	1365	752	290	56	495	173	239	10400	31860	6739
21	6110	920	1364	753	290	56	494	174	240	10400	31861	6737
22	6111	917	1364	753	289	56	494	175	241	10400	31861	6733
23	6111	916	1363	754	287	56	495	175	243	10400	31860	6729
24	6112	915	1362	756	283	56	495	177	244	10400	31870	6722
25	6114	914	1361	756	282	56	495	177	245	10400	31860	6718
26	6114	914	1361	756	281	56	495	178	245	10400	31861	6716
27	6115	912	1361	756	280	56	495	178	246	10400	31860	6713
28	6115	910	1360	757	280	56	495	180	247	10400	31861	6710
29	6115	908	1360	757	280	56	495	182	247	10400	31860	6709
30	6117	907	1358	757	280	56	495	183	247	10400	31860	6705
31	6118	906	1355	759	280	56	495	183	248	10400	31876	6702
32	6119	906	1353	760	280	56	495	183	248	10400	31872	6699
33	6120	904	1351	760	280	56	497	184	249	10400	31860	6694
34	6120	903	1349	760	280	56	496	185	251	10400	31861	6691
35	6124	899	1331	770	280	56	500	188	252	10400	31928	6670
36	6126	898	1327	767	280	56	501	191	254	10400	31870	6660
37	6128	895	1326	767	280	56	501	192	255	10400	31861	6655
38	6129	893	1326	767	280	56	500	193	256	10400	31862	6654
39	6130	893	1326	767	280	56	500	193	257	10400	31860	6653
40	6131	892	1325	768	280	56	500	192	258	10400	31861	6651
41	6133	890	1324	768	280	56	498	192	259	10400	31861	6648
42	6133	888	1322	769	280	56	499	193	259	10400	31861	6645
43	6133	887	1322	769	280	56	499	194	260	10400	31861	6643
44	6135	887	1321	769	280	56	498	195	260	10400	31861	6642
45	6135	886	1321	769	280	56	499	194	261	10400	31860	6641
46	6136	886	1320	770	280	56	498	194	261	10400	31871	6640
47	6137	883	1319	770	280	56	498	195	262	10400	31861	6637
48	6137	883	1318	770	280	56	497	195	263	10400	31867	6636
49	6138	881	1316	770	280	56	497	195	266	10400	31860	6631
50	6139	881	1316	770	280	56	496	195	266	10400	31861	6631
51	6142	880	1315	771	280	56	492	195	268	10400	31862	6629
52	6144	879	1315	771	280	56	491	195	270	10400	31860	6627
53	6143	879	1314	771	280	56	491	195	271	10400	31861	6626
54	6144	879	1314	771	280	56	490	195	272	10400	31860	6625
55	6144	878	1314	771	280	56	489	195	274	10400	31860	6624
56	6145	877	1314	771	280	56	488	195	274	10400	31860	6624
57	6145	877	1314	771	280	56	487	195	275	10400	31860	6623
58	6145	877	1314	771	280	56	487	195	275	10400	31860	6623
59	6145	877	1313	771	280	56	487	195	276	10400	31860	6622
60	6145	877	1313	771	280	56	487	195	276	10400	31860	6622
61	6147	877	1313	771	280	56	485	195	276	10400	31860	6622
62	6147	877	1313	771	280	56	485	195	276	10400	31860	6622
63	6147	875	1313	771	280	56	483	195	280	10400	31862	6620
64	6148	875	1313	771	280	56	482	195	280	10400	31860	6619
65	6148	875	1313	771	280	56	482	195	280	10400	31860	6619
66	6149	875	1313	771	280	56	481	195	280	10400	31860	6619
67	6150	875	1313	771	280	56	480	195	281	10400	31860	6619
68	6150	874	1313	771	280	56	480	195	281	10400	31860	6619
69	6150	874	1313	771	280	56	480	195	281	10400	31860	6618
70	6150	874	1313	771	280	56	479	195	282	10400	31861	6618
71	6151	874	1312	771	280	56	477	195	283	10400	31861	6618
72	6151	874	1312	771	280	56	477	195	284	10400	31860	6617
73	6151	874	1312	771	280	56	477	195	284	10400	31860	6617
74	6153	874	1312	771	280	56	475	195	284	10400	31860	6617
75	6154	874	1312	771	280	56	472	195	286	10400	31862	6616
76	6156	872	1311	771	280	56	469	195	290	10400	31860	6613
77	6157	872	1311	771	280	56	468	195	290	10400	31861	6613
78	6157	871	1311	771	280	56	468	195	291	10400	31860	6612
79	6158	871	1311	771	280	56	467	195	291	10400	31861	6612
80	6159	871	1311	771	280	56	466	195	292	10400	31861	6611
81	6159	871	1311	771	280	56	464	195	293	10400	31862	6611
82	6159	870	1310	771	280	56	464	195	294	10400	31860	6610
83	6159	870	1310	771	280	56	464	195	294	10400	31860	6610
84	6160	870	1310	771	280	56	463	195	294	10400	31860	6610
85	6161	870	1310	771	280	56	463	195	294	10400	31860	6610
86	6162	870	1310	771	280	56	462	195	294	10400	31860	6610
87	6162	870	1310	771	280	56	460	195	295	10400	31861	6609
88	6163	870	1310	771	280	56	460	195	295	10400	31860	6608
89	6163	870	1310	771	280	56	460	195	296	10400	31860	6608
90	6164	870	1310	771	280	56	458	195	296	10400	31860	6608
91	6165	869	1310	771	280	56	457	195	296	10400	31860	6608
92	6166	869	1310	771	280	56	457	195	296	10400	31860	6608
93	6167	869	1310	771	280	56	456	195	296	10400	31860	6608
94	6167	869	1309	771	280	56	455	195	297	10400	31861	6607

95	6167	868	1309	771	280	56	455	195	298	10400	31860	6606
96	6167	868	1309	771	280	56	455	195	298	10400	31860	6606
97	6168	868	1309	771	280	56	455	195	298	10400	31860	6606
98	6168	868	1309	771	280	56	455	195	298	10400	31860	6606
99	6168	867	1309	771	280	56	456	195	298	10400	31860	6605
100	6169	864	1310	771	280	56	455	195	298	10400	31860	6604
101	6170	864	1310	771	280	56	455	195	299	10400	31860	6604
102	6171	864	1310	771	280	56	454	195	299	10400	31860	6604
103	6171	864	1310	771	280	56	454	195	299	10400	31860	6604
104	6172	863	1310	771	280	56	453	195	299	10400	31861	6603
105	6174	863	1310	771	280	56	452	195	299	10400	31860	6603
106	6174	863	1310	771	280	56	452	195	299	10400	31860	6603

Table A.8 Run-by-Run Results of the GA for the 35% Variation Bound

Run No	Residential	Office	Destination	Retail	Convention	Cinema	Hotel	Community Facility	School	Total Area	Person Trip	Vehicle Trip
1	5832	674	1756	774	307	78	560	202	218	10400	34146	7257
2	5835	671	1756	773	306	74	563	201	220	10400	34083	7241
3	5836	674	1754	775	301	66	566	202	224	10400	33996	7210
4	5838	674	1752	775	297	63	572	202	227	10400	33930	7191
5	5842	676	1748	775	296	56	576	202	231	10400	33804	7160
6	5844	677	1745	774	295	54	576	202	232	10400	33767	7150
7	5850	677	1736	776	292	52	579	202	234	10400	33720	7129
8	5854	675	1734	774	285	52	583	202	241	10400	33638	7108
9	5860	675	1731	772	280	52	585	202	242	10400	33572	7094
10	5862	676	1729	772	277	52	585	202	245	10400	33541	7086
11	5867	674	1726	772	273	52	586	202	247	10400	33503	7073
12	5870	674	1718	770	273	52	586	202	255	10400	33439	7057
13	5875	674	1714	770	268	52	588	202	257	10400	33393	7043
14	5879	675	1708	768	266	52	591	201	260	10400	33325	7029
15	5881	674	1706	769	262	52	593	202	261	10400	33309	7020
16	5882	673	1704	770	261	52	594	201	263	10400	33307	7014
17	5887	670	1699	767	260	52	596	202	266	10400	33234	7000
18	5888	670	1697	766	260	52	598	202	268	10400	33210	6995
19	5890	669	1694	764	260	52	599	202	269	10400	33171	6989
20	5893	670	1690	762	260	52	598	202	273	10400	33115	6980
21	5898	668	1686	760	260	52	599	202	275	10400	33071	6971
22	5901	668	1683	759	260	52	600	202	274	10400	33040	6966
23	5902	665	1682	758	260	52	603	200	278	10400	33013	6960
24	5903	665	1677	756	260	52	606	201	281	10400	32944	6949
25	5905	661	1674	753	260	52	606	202	286	10400	32894	6939
26	5908	661	1672	753	260	52	607	200	287	10400	32885	6936
27	5910	660	1671	753	260	52	607	201	286	10400	32872	6933
28	5913	658	1667	752	260	52	610	200	289	10400	32826	6923
29	5914	656	1665	752	260	52	611	200	291	10400	32821	6919
30	5914	655	1664	751	260	52	611	202	292	10400	32798	6915
31	5920	652	1658	748	260	52	613	202	296	10400	32728	6901
32	5924	647	1653	748	260	52	614	202	299	10400	32695	6888
33	5927	647	1648	748	260	52	616	201	300	10400	32665	6881
34	5929	646	1646	746	260	52	618	201	302	10400	32621	6875
35	5930	646	1644	743	260	52	620	202	302	10400	32572	6869
36	5933	644	1641	742	260	52	623	202	303	10400	32542	6861
37	5937	642	1635	740	260	52	626	202	305	10400	32464	6848
38	5942	642	1632	735	260	52	629	202	307	10400	32371	6837
39	5945	639	1627	733	260	52	631	201	310	10400	32326	6827
40	5947	640	1623	732	260	52	633	202	310	10400	32281	6820
41	5951	638	1620	730	260	52	636	202	310	10400	32241	6812
42	5954	638	1617	729	260	52	636	202	310	10400	32206	6806
43	5956	638	1615	729	260	52	638	201	310	10400	32199	6803
44	5958	638	1612	728	260	52	639	202	310	10400	32166	6797
45	5959	640	1608	728	260	52	640	202	310	10400	32140	6793
46	5963	637	1605	726	260	52	743	104	310	10400	31862	6782
47	5964	636	1604	726	260	52	743	105	310	10400	31860	6780
48	5964	636	1604	726	260	52	743	105	310	10400	31860	6780
49	5965	635	1604	726	260	52	742	106	310	10400	31860	6779
50	5965	634	1604	726	260	52	742	107	310	10400	31860	6777
51	5967	632	1603	726	260	52	742	108	310	10400	31861	6775
52	5968	631	1603	726	260	52	740	108	310	10400	31861	6774
53	5969	631	1601	727	260	52	740	109	310	10400	31862	6773
54	5969	630	1600	728	260	52	741	109	310	10400	31871	6771
55	5970	629	1599	727	260	52	742	110	310	10400	31860	6768
56	5970	629	1598	728	260	52	742	110	310	10400	31860	6766
57	5972	629	1598	728	260	52	741	110	310	10400	31860	6766
58	5972	629	1595	729	260	52	742	111	310	10400	31864	6763
59	5972	627	1593	730	260	52	743	112	310	10400	31869	6760
60	5973	627	1592	730	260	52	744	112	310	10400	31860	6757
61	5974	626	1592	730	260	52	743	113	310	10400	31861	6756
62	5975	625	1591	730	260	52	743	113	310	10400	31860	6755
63	5975	625	1590	731	260	52	744	112	310	10400	31869	6754
64	5975	622	1588	731	260	52	746	115	310	10400	31861	6749
65	5976	621	1588	731	260	52	746	115	310	10400	31861	6748
66	5976	622	1586	732	260	52	747	115	310	10400	31860	6746
67	5977	621	1583	734	260	52	749	115	310	10400	31868	6741
68	5980	621	1579	734	260	52	747	117	310	10400	31865	6737
69	5980	620	1577	735	260	52	748	117	310	10400	31860	6733
70	5981	620	1576	735	260	52	749	117	310	10400	31861	6732
71	5981	620	1576	735	260	52	749	117	310	10400	31860	6732
72	5981	619	1573	736	260	52	749	118	310	10400	31861	6729
73	5983	618	1573	736	260	52	749	118	310	10400	31860	6727
74	5984	617	1571	737	260	52	750	120	309	10400	31862	6724
75	5985	616	1570	737	260	52	749	121	310	10400	31860	6721
76	5986	616	1570	737	260	52	749	121	310	10400	31860	6721
77	5986	614	1568	738	260	52	750	122	310	10400	31862	6718
78	5987	612	1566	738	260	52	750	124	310	10400	31860	6713
79	5987	611	1565	738	260	52	750	126	310	10400	31860	6712
80	5988	610	1563	739	260	52	751	127	310	10400	31863	6707
81	5990	609	1562	739	260	52	750	127	310	10400	31861	6706
82	5991	609	1561	740	260	52	749	128	310	10400	31871	6705
83	5993	608	1560	740	260	52	749	127	310	10400	31860	6703
84	5995	607	1558	741	260	52	750	128	309	10400	31863	6699
85	5996	607	1556	741	260	52	750	129	309	10400	31861	6696
86	5996	606	1554	742	260	52	751	129	310	10400	31860	6693
87	5996	606	1554	742	260	52	751	129	310	10400	31860	6693
88	5997	605	1553	743	260	52	751	129	310	10400	31866	6691
89	5997	604	1551	743	260	52	752	131	310	10400	31860	6688
90	5997	603	1550	743	260	52	752	132	310	10400	31860	6687
91	6000	601	1550	743	260	52	750	133	310	10400	31861	6684
92	6001	599	1547	745	260	52	752	134	310	10400	31874	6680
93	6002	599	1545	746	260	52	752	134	310	10400	31875	6677
94	6003	598	1543	745	260	52	752	136	310	10400	31860	6674

95	6003	598	1543	745	260	52	752	136	310	10400	31860	6674
96	6003	596	1543	745	260	52	753	137	310	10400	31860	6672
97	6004	596	1542	746	260	52	753	136	310	10400	31869	6671
98	6007	595	1540	747	260	52	751	137	310	10400	31871	6667
99	6009	593	1539	747	260	52	753	137	310	10400	31863	6665
100	6010	592	1537	748	260	52	753	138	310	10400	31871	6661
101	6138	593	1537	748	260	52	625	137	310	10400	31900	6651
102	6141	593	1531	748	260	52	626	140	310	10400	31871	6642
103	6142	592	1529	747	260	52	626	140	310	10400	31860	6639
104	6144	591	1527	748	260	52	626	141	310	10400	31865	6635
105	6147	590	1526	749	260	52	625	141	310	10400	31864	6633
106	6147	590	1526	749	260	52	625	141	310	10400	31860	6633
107	6147	589	1526	749	260	52	625	142	310	10400	31860	6632
108	6147	588	1526	749	260	52	625	142	310	10400	31860	6631
109	6148	588	1525	749	260	52	625	143	310	10400	31860	6630
110	6148	588	1525	749	260	52	625	143	310	10400	31860	6630
111	6148	587	1525	749	260	52	625	144	310	10400	31860	6628
112	6149	586	1525	749	260	52	624	144	310	10400	31861	6627
113	6150	585	1524	749	260	52	625	145	310	10400	31860	6626
114	6150	585	1524	749	260	52	625	145	310	10400	31860	6626
115	6150	584	1524	749	260	52	625	145	310	10400	31860	6625
116	6151	583	1523	750	260	52	625	145	310	10400	31860	6624
117	6152	583	1522	750	260	52	625	146	309	10400	31863	6622
118	6155	580	1520	751	260	52	625	148	310	10400	31860	6617
119	6155	580	1519	751	260	52	625	148	310	10400	31860	6616
120	6155	579	1519	751	260	52	625	148	310	10400	31863	6615
121	6156	577	1519	751	260	52	625	149	310	10400	31860	6613
122	6156	577	1517	752	260	52	626	150	310	10400	31869	6611
123	6157	576	1514	753	260	52	628	151	310	10400	31860	6606
124	6157	575	1512	753	260	52	628	152	310	10400	31860	6604
125	6158	573	1511	754	260	52	628	153	310	10400	31870	6602
126	6159	572	1511	754	260	52	630	153	310	10400	31860	6599
127	6159	571	1510	754	260	52	630	153	310	10400	31860	6598
128	6159	571	1510	754	260	52	630	153	310	10400	31860	6598
129	6159	571	1509	754	260	52	630	153	310	10400	31861	6597
130	6160	572	1507	755	260	52	630	154	310	10400	31861	6594
131	6161	570	1507	755	260	52	629	156	310	10400	31861	6592
132	6163	570	1504	756	260	52	630	156	309	10400	31860	6589
133	6165	568	1503	757	260	52	629	156	310	10400	31867	6587
134	6166	567	1500	758	260	52	630	158	310	10400	31869	6582
135	6166	567	1500	757	260	52	630	158	310	10400	31860	6581
136	6168	566	1497	758	260	52	631	158	310	10400	31860	6578
137	6168	565	1496	759	260	52	631	159	310	10400	31865	6575
138	6169	564	1494	760	260	52	630	161	310	10400	31871	6572
139	6171	562	1492	760	260	52	631	161	310	10400	31861	6568
140	6172	561	1490	761	260	52	633	162	310	10400	31867	6565
141	6174	558	1488	761	260	52	633	163	310	10400	31862	6560
142	6176	558	1486	762	260	52	633	164	310	10400	31860	6556
143	6176	557	1484	762	260	52	633	164	310	10400	31860	6555
144	6176	554	1484	763	260	52	633	167	310	10400	31861	6552
145	6177	553	1483	764	260	52	633	168	310	10400	31871	6550
146	6178	553	1481	763	260	52	634	168	310	10400	31860	6547
147	6180	551	1478	765	260	52	634	169	310	10400	31863	6542
148	6181	550	1477	765	260	52	635	171	310	10400	31860	6540
149	6182	549	1477	765	260	52	634	171	310	10400	31861	6539
150	6182	548	1477	765	260	52	634	172	310	10400	31860	6537
151	6184	546	1477	765	260	52	633	173	310	10400	31861	6536
152	6184	546	1475	765	260	52	633	174	310	10400	31860	6533
153	6184	544	1474	766	260	52	634	176	310	10400	31863	6531
154	6184	539	1473	766	260	52	636	179	310	10400	31861	6526
155	6185	539	1473	766	260	52	636	179	310	10400	31860	6525
156	6187	538	1473	766	260	52	634	180	310	10400	31860	6524
157	6188	536	1469	769	260	52	633	182	310	10400	31885	6520
158	6190	536	1467	768	260	52	634	183	310	10400	31862	6515
159	6191	535	1465	768	260	52	633	185	310	10400	31860	6512
160	6192	535	1464	768	260	52	633	185	310	10400	31860	6511
161	6194	533	1462	769	260	52	633	186	310	10400	31863	6507
162	6194	532	1462	769	260	52	634	186	310	10400	31861	6506
163	6195	531	1461	770	260	52	634	187	310	10400	31860	6505
164	6195	531	1461	770	260	52	634	187	310	10400	31860	6503
165	6196	531	1460	770	260	52	633	187	310	10400	31861	6502
166	6199	529	1458	771	260	52	633	187	310	10400	31864	6499
167	6200	529	1456	772	260	52	633	188	310	10400	31861	6496
168	6200	528	1456	772	260	52	633	188	310	10400	31861	6495
169	6201	528	1451	774	260	52	634	189	310	10400	31876	6490
170	6202	527	1450	773	260	52	635	190	310	10400	31860	6487
171	6203	526	1448	774	260	52	635	191	310	10400	31868	6485
172	6205	525	1447	774	260	52	635	191	310	10400	31860	6482
173	6206	525	1447	774	260	52	634	191	310	10400	31860	6482
174	6207	524	1447	774	260	52	634	191	310	10400	31861	6481
175	6209	524	1444	775	260	52	633	193	310	10400	31861	6477
176	6210	523	1442	776	260	52	634	193	310	10400	31862	6474
177	6210	523	1441	776	260	52	634	194	310	10400	31861	6472
178	6210	522	1441	776	260	52	635	193	310	10400	31861	6471
179	6211	520	1439	777	260	52	637	193	310	10400	31862	6467
180	6214	519	1438	777	260	52	635	194	310	10400	31860	6466
181	6214	519	1438	777	260	52	635	194	310	10400	31860	6466
182	6214	518	1438	778	260	52	636	195	310	10400	31861	6464
183	6216	515	1437	778	260	52	636	196	310	10400	31862	6461
184	6218	514	1434	779	260	52	636	197	310	10400	31860	6457
185	6218	512	1434	779	260	52	636	199	310	10400	31860	6455
186	6218	511	1434	779	260	52	636	199	310	10400	31860	6454
187	6219	508	1433	779	260	52	637	201	310	10400	31860	6450
188	6220	507	1432	780	260	52	637	201	310	10400	31863	6449
189	6221	507	1432	780	260	52	637	201	310	10400	31860	6448
190	6222	507	1430	780	260	52	636	202	310	10400	31860	6446
191	6223	507	1430	780	260	52	635	202	310	10400	31860	6446

192	6224	507	1429	780	260	52	634	202	310	10400	31860	6445
193	6224	507	1428	781	260	52	634	202	310	10400	31871	6444
194	6226	507	1428	781	260	52	633	202	310	10400	31866	6443
195	6227	507	1425	783	260	52	634	202	310	10400	31877	6440
196	6229	507	1423	782	260	52	634	202	310	10400	31860	6437
197	6229	507	1423	782	260	52	634	202	310	10400	31860	6437
198	6229	507	1423	782	260	52	634	202	310	10400	31860	6437
199	6229	507	1423	783	260	52	634	202	310	10400	31860	6436

Table A.9 Run-by-Run Results of the GA for the 40% Variation Bound

Run No	Residential	Office	Destination	Retail	Convention	Cinema	Hotel	Community Facility	School	Total Area	Person Trip	Vehicle Trip
1	5850	780	1757	594	400	88	560	197	174	10400	32008	7359
2	5853	780	1752	594	399	83	562	200	177	10400	31924	7334
3	5855	778	1752	595	399	77	565	201	179	10400	31863	7314
4	5856	778	1752	596	395	77	565	202	179	10400	31860	7309
5	5857	776	1751	597	394	77	566	204	179	10400	31860	7304
6	5860	775	1751	598	393	75	565	203	179	10400	31860	7299
7	5860	774	1750	600	391	74	565	205	180	10400	31863	7291
8	5862	772	1749	603	388	71	566	208	182	10400	31862	7277
9	5862	771	1748	606	386	68	567	209	183	10400	31860	7266
10	5865	768	1748	611	382	65	568	209	184	10400	31862	7251
11	5867	768	1747	612	380	64	568	210	185	10400	31860	7245
12	5867	767	1747	613	378	63	567	210	187	10400	31867	7240
13	5807	610	1691	826	309	56	703	147	252	10400	34171	7093
14	6021	505	1687	824	291	80	583	150	259	10400	34205	7021
15	6022	505	1686	823	291	77	584	151	261	10400	34157	7012
16	6024	504	1685	822	289	73	586	153	266	10400	34084	6992
17	6026	502	1682	820	286	71	589	156	267	10400	34010	6975
18	6028	503	1682	820	285	67	590	157	268	10400	33940	6960
19	6031	502	1679	818	283	63	594	159	271	10400	33849	6938
20	6034	501	1677	818	281	58	597	161	273	10400	33771	6915
21	6037	499	1675	816	279	56	598	161	277	10400	33700	6901
22	6043	501	1672	812	274	49	602	167	281	10400	33520	6861
23	6048	501	1666	811	265	48	607	170	284	10400	33426	6835
24	6052	500	1662	807	262	48	610	172	287	10400	33333	6818
25	6054	497	1656	806	258	48	615	175	291	10400	33269	6799
26	6060	496	1646	805	251	48	621	179	295	10400	33171	6770
27	6063	497	1642	802	249	48	622	180	297	10400	33107	6758
28	6064	495	1641	801	247	48	623	180	300	10400	33080	6752
29	6065	495	1637	801	244	48	626	181	303	10400	33039	6739
30	6071	495	1633	798	240	48	628	183	304	10400	32966	6724
31	6072	495	1630	797	240	48	628	184	304	10400	32938	6719
32	6074	492	1628	795	240	48	629	185	311	10400	32881	6708
33	6074	490	1625	794	240	48	629	185	314	10400	32862	6703
34	6076	489	1622	792	240	48	631	185	317	10400	32818	6695
35	6078	487	1617	789	240	48	634	186	320	10400	32748	6684
36	6082	487	1615	787	240	48	634	187	320	10400	32703	6677
37	6087	484	1613	786	240	48	636	187	321	10400	32661	6669
38	6091	483	1609	779	240	48	640	188	321	10400	32543	6656
39	6094	482	1605	776	240	48	642	191	322	10400	32474	6647
40	6097	481	1604	775	240	48	642	191	322	10400	32450	6643
41	6098	480	1602	774	240	48	644	191	322	10400	32435	6639
42	6100	478	1596	774	240	48	648	193	322	10400	32397	6628
43	6101	477	1595	773	240	48	650	195	322	10400	32380	6624
44	6104	474	1594	772	240	48	650	196	322	10400	32354	6619
45	6107	474	1591	770	240	48	651	197	321	10400	32305	6612
46	6110	472	1590	767	240	48	651	200	322	10400	32263	6606
47	6115	471	1587	765	240	48	651	201	322	10400	32207	6599
48	6121	469	1583	762	240	48	652	203	322	10400	32141	6588
49	6121	468	1581	760	240	48	654	205	322	10400	32104	6582
50	6128	468	1576	755	240	48	655	208	322	10400	32006	6570
51	6130	469	1573	753	240	48	658	208	322	10400	31954	6563
52	6133	468	1568	752	240	48	660	209	322	10400	31915	6555
53	6135	469	1561	751	240	48	664	210	322	10400	31863	6544
54	6135	469	1560	751	240	48	664	210	322	10400	31870	6542
55	6138	468	1556	752	240	48	665	210	322	10400	31864	6537
56	6138	468	1556	752	240	48	666	210	322	10400	31860	6536
57	6139	468	1552	755	240	48	666	210	322	10400	31881	6532
58	6141	468	1549	755	240	48	667	210	322	10400	31877	6529
59	6143	468	1547	755	240	48	667	210	322	10400	31860	6525
60	6143	468	1547	755	240	48	667	210	322	10400	31860	6525
61	6143	469	1545	756	240	48	667	210	322	10400	31868	6524
62	6144	470	1543	756	240	48	668	209	322	10400	31860	6521
63	6146	470	1543	756	240	48	666	209	322	10400	31860	6521
64	6146	469	1542	757	240	48	666	209	322	10400	31860	6520
65	6146	469	1542	757	240	48	666	210	322	10400	31860	6520
66	6147	468	1541	757	240	48	666	210	322	10400	31860	6518
67	6148	468	1540	757	240	48	667	210	322	10400	31861	6517
68	6149	468	1540	758	240	48	667	209	322	10400	31863	6516
69	6151	468	1538	758	240	48	666	209	321	10400	31861	6514
70	6152	468	1538	758	240	48	666	209	321	10400	31860	6514
71	6152	468	1534	760	240	48	668	209	321	10400	31862	6509
72	6152	468	1531	761	240	48	669	209	322	10400	31866	6506
73	6153	468	1528	762	240	48	669	210	322	10400	31870	6502
74	6154	468	1526	762	240	48	670	210	322	10400	31866	6499
75	6156	468	1524	762	240	48	669	210	322	10400	31860	6497
76	6156	468	1524	762	240	48	669	210	322	10400	31860	6497
77	6156	468	1524	762	240	48	669	210	322	10400	31860	6497
78	6156	468	1522	764	240	48	670	210	322	10400	31869	6495
79	6156	468	1520	764	240	48	671	210	322	10400	31871	6493
80	6158	468	1518	765	240	48	672	210	321	10400	31860	6489
81	6158	468	1518	765	240	48	672	210	321	10400	31860	6489
82	6159	468	1518	765	240	48	671	210	321	10400	31860	6489
83	6160	469	1515	765	240	48	671	210	322	10400	31860	6487
84	6162	468	1513	766	240	48	671	210	322	10400	31866	6484
85	6162	468	1512	766	240	48	671	210	322	10400	31860	6483
86	6163	468	1512	766	240	48	671	210	322	10400	31860	6482
87	6163	468	1511	767	240	48	671	210	322	10400	31871	6482
88	6164	468	1510	767	240	48	671	210	322	10400	31861	6480
89	6164	468	1510	767	240	48	671	210	322	10400	31860	6480
90	6164	468	1509	767	240	48	671	210	322	10400	31861	6479
91	6165	468	1508	768	240	48	672	210	322	10400	31860	6476
92	6165	468	1508	768	240	48	672	210	322	10400	31860	6476
93	6165	468	1507	768	240	48	672	210	322	10400	31860	6476
94	6167	468	1507	768	240	48	670	210	322	10400	31860	6476

95	6168	468	1507	768	240	48	670	210	322	10400	31860	6475
96	6168	468	1506	768	240	48	670	210	322	10400	31860	6475
97	6169	468	1504	769	240	48	670	210	322	10400	31860	6472
98	6171	468	1501	770	240	48	671	209	322	10400	31864	6468
99	6171	468	1499	770	240	48	671	210	322	10400	31861	6466
100	6171	468	1499	771	240	48	671	210	322	10400	31860	6466
101	6173	468	1499	771	240	48	670	210	322	10400	31860	6465
102	6174	468	1498	771	240	48	669	210	322	10400	31862	6465
103	6174	468	1498	771	240	48	669	210	322	10400	31860	6464
104	6174	468	1497	771	240	48	669	210	322	10400	31860	6463
105	6174	468	1497	771	240	48	669	210	322	10400	31860	6463
106	6174	468	1496	772	240	48	671	209	322	10400	31867	6462
107	6176	468	1495	772	240	48	670	209	322	10400	31860	6461
108	6176	468	1494	773	240	48	670	209	322	10400	31871	6460
109	6182	469	1491	774	240	48	670	206	321	10400	31864	6456
110	6185	469	1488	774	240	48	667	207	322	10400	31862	6453
111	6185	468	1487	775	240	48	668	208	322	10400	31860	6450
112	6185	468	1486	775	240	48	668	208	322	10400	31861	6450
113	6187	468	1486	775	240	48	667	208	322	10400	31860	6449
114	6190	468	1485	775	240	48	665	208	322	10400	31860	6447
115	6190	468	1484	776	240	48	665	208	322	10400	31860	6446
116	6191	468	1481	776	240	48	665	208	322	10400	31861	6444
117	6191	468	1479	777	240	48	665	210	322	10400	31864	6441
118	6195	468	1473	779	240	48	666	209	322	10400	31866	6434
119	6196	468	1473	779	240	48	665	209	322	10400	31860	6433
120	6197	468	1473	779	240	48	664	209	322	10400	31860	6432
121	6197	468	1473	779	240	48	664	209	322	10400	31860	6432
122	6197	468	1472	779	240	48	664	209	322	10400	31860	6432
123	6198	468	1467	781	240	48	665	210	322	10400	31869	6427
124	6200	469	1465	781	240	48	665	210	322	10400	31860	6423
125	6201	470	1462	782	240	48	665	210	322	10400	31862	6420
126	6203	469	1462	782	240	48	664	210	322	10400	31861	6420
127	6203	470	1460	783	240	48	664	210	322	10400	31867	6419
128	6204	470	1460	783	240	48	664	209	322	10400	31862	6418
129	6205	469	1459	783	240	48	664	210	322	10400	31860	6417
130	6206	469	1457	784	240	48	664	210	321	10400	31870	6414
131	6209	468	1456	784	240	48	663	210	321	10400	31863	6412
132	6211	468	1453	785	240	48	664	210	321	10400	31861	6408
133	6211	468	1453	785	240	48	664	210	322	10400	31860	6408
134	6211	468	1452	785	240	48	664	210	322	10400	31860	6406
135	6211	468	1451	786	240	48	663	210	322	10400	31871	6406
136	6213	468	1450	786	240	48	664	210	322	10400	31860	6404
137	6214	468	1448	787	240	48	664	210	322	10400	31860	6401
138	6215	468	1448	787	240	48	663	210	322	10400	31860	6401
139	6215	468	1447	787	240	48	663	210	322	10400	31862	6401
140	6215	468	1447	787	240	48	663	210	322	10400	31860	6400
141	6218	468	1445	787	240	48	661	210	322	10400	31860	6398
142	6218	468	1445	788	240	48	661	210	322	10400	31860	6397
143	6219	468	1445	788	240	48	661	210	322	10400	31860	6397
144	6219	468	1445	788	240	48	661	210	322	10400	31860	6397
145	6219	468	1444	788	240	48	661	210	322	10400	31860	6397
146	6219	468	1444	788	240	48	661	210	322	10400	31860	6397
147	6220	468	1443	788	240	48	661	210	322	10400	31861	6395
148	6220	468	1443	788	240	48	661	210	322	10400	31860	6395
149	6220	468	1443	788	240	48	661	210	322	10400	31860	6394
150	6220	468	1442	788	240	48	661	210	322	10400	31860	6394

Table A.10 Run-by-Run Results of the GA for the 45% Variation Bound

Run No	Residential	Office	Destination	Retail	Convention	Cinema	Hotel	Community Facility	School	Total Area	Person Trip	Vehicle Trip
1	5850	779	1757	599	401	82	561	141	230	10400	31965	7343
2	5851	781	1756	599	399	77	562	143	232	10400	31888	7322
3	5853	778	1753	599	398	75	562	145	237	10400	31860	7308
4	5855	797	1753	749	226	72	562	147	239	10400	33375	7177
5	5858	798	1750	747	224	67	563	152	242	10400	33272	7152
6	6346	820	1457	788	243	67	359	87	232	10400	32493	6764
7	6349	821	1454	787	237	64	359	93	235	10400	32417	6740
8	6351	822	1453	788	234	58	363	95	235	10400	32350	6718
9	6355	820	1452	787	230	54	365	96	241	10400	32254	6694
10	6355	818	1451	785	229	53	367	99	244	10400	32195	6682
11	6357	817	1450	786	228	47	369	100	246	10400	32137	6662
12	6360	817	1447	786	225	45	371	102	248	10400	32086	6647
13	6364	816	1444	784	220	44	371	106	251	10400	32022	6629
14	6369	813	1439	778	220	44	374	107	256	10400	31906	6612
15	6371	810	1437	776	220	44	374	109	258	10400	31860	6605
16	6371	810	1436	777	220	44	373	109	259	10400	31871	6604
17	6372	810	1435	777	220	44	374	110	259	10400	31860	6601
18	6372	809	1435	777	220	44	373	110	260	10400	31861	6600
19	6373	809	1434	777	220	44	373	110	261	10400	31860	6600
20	6373	808	1434	777	220	44	373	111	261	10400	31860	6598
21	6373	807	1431	778	220	44	373	109	263	10400	31868	6594
22	6373	807	1430	778	220	44	375	109	264	10400	31860	6592
23	6374	807	1430	778	220	44	375	109	264	10400	31860	6592
24	6375	806	1429	778	220	44	374	110	264	10400	31860	6591
25	6375	806	1429	779	220	44	374	110	264	10400	31860	6590
26	6375	805	1428	779	220	44	374	111	264	10400	31860	6589
27	6375	805	1428	779	220	44	374	111	265	10400	31860	6589
28	6375	804	1428	779	220	44	373	111	266	10400	31860	6588
29	6377	802	1428	779	220	44	371	113	266	10400	31862	6585
30	6379	799	1426	779	220	44	372	114	267	10400	31862	6581
31	6379	799	1424	780	220	44	372	116	266	10400	31866	6579
32	6379	796	1422	781	220	44	372	120	266	10400	31871	6573
33	6380	793	1421	781	220	44	373	121	267	10400	31860	6570
34	6380	793	1420	781	220	44	373	121	267	10400	31861	6569
35	6382	792	1420	781	220	44	372	122	267	10400	31862	6567
36	6382	792	1419	781	220	44	372	122	268	10400	31860	6566
37	6383	792	1419	781	220	44	371	122	268	10400	31860	6566
38	6383	791	1419	782	220	44	372	122	268	10400	31862	6565
39	6384	791	1417	782	220	44	372	122	269	10400	31860	6563
40	6384	790	1416	782	220	44	371	124	269	10400	31861	6560
41	6384	789	1415	782	220	44	370	125	270	10400	31860	6559
42	6384	788	1414	782	220	44	371	126	270	10400	31860	6557
43	6385	786	1413	783	220	44	370	128	271	10400	31860	6554
44	6385	785	1413	783	220	44	369	129	272	10400	31860	6553
45	6386	784	1412	783	220	44	369	130	273	10400	31862	6550
46	6385	783	1411	783	220	44	369	131	273	10400	31861	6548
47	6385	782	1411	783	220	44	369	131	273	10400	31860	6548
48	6385	781	1411	783	220	44	368	132	275	10400	31861	6546
49	6388	778	1409	784	220	44	368	133	276	10400	31860	6541
50	6388	776	1408	784	220	44	368	135	277	10400	31860	6538
51	6388	776	1408	784	220	44	368	135	277	10400	31860	6538
52	6390	776	1407	784	220	44	366	135	278	10400	31861	6537
53	6391	775	1404	785	220	44	366	135	278	10400	31860	6533
54	6391	775	1404	785	220	44	367	136	278	10400	31860	6532
55	6392	773	1404	785	220	44	367	137	279	10400	31860	6530
56	6395	770	1402	786	220	44	364	140	280	10400	31862	6525
57	6396	769	1402	786	220	44	363	141	280	10400	31860	6523
58	6397	768	1399	787	220	44	364	141	281	10400	31862	6519
59	6396	767	1397	787	220	44	365	141	282	10400	31862	6517
60	6397	766	1396	788	220	44	365	143	283	10400	31860	6514
61	6397	764	1396	788	220	44	365	143	284	10400	31861	6512
62	6397	764	1395	788	220	44	364	143	285	10400	31860	6511
63	6398	763	1395	788	220	44	363	143	285	10400	31860	6511
64	6398	762	1395	788	220	44	362	144	287	10400	31861	6509
65	6401	758	1392	789	220	44	360	147	290	10400	31860	6501
66	6402	757	1391	789	220	44	359	148	290	10400	31860	6499
67	6402	757	1391	789	220	44	359	148	291	10400	31860	6499
68	6403	756	1391	789	220	44	358	149	291	10400	31860	6498
69	6404	753	1390	789	220	44	358	150	291	10400	31860	6495
70	6406	752	1390	789	220	44	357	152	291	10400	31861	6493
71	6406	750	1387	790	220	44	357	153	293	10400	31862	6488
72	6408	748	1381	792	220	44	356	154	296	10400	31865	6480
73	6409	747	1381	792	220	44	356	154	297	10400	31860	6477
74	6411	746	1380	792	220	44	354	155	298	10400	31860	6476
75	6411	745	1380	792	220	44	354	155	298	10400	31860	6475
76	6411	745	1380	792	220	44	354	156	298	10400	31860	6474
77	6411	745	1380	792	220	44	354	156	298	10400	31860	6474
78	6411	744	1376	793	220	44	354	157	300	10400	31867	6470
79	6413	742	1376	793	220	44	354	158	300	10400	31861	6468
80	6414	741	1375	794	220	44	354	158	301	10400	31860	6465
81	6415	741	1374	794	220	44	353	158	302	10400	31861	6464
82	6416	739	1372	795	220	44	351	158	306	10400	31864	6459
83	6417	737	1371	795	220	44	351	159	306	10400	31860	6456
84	6417	736	1371	795	220	44	351	159	307	10400	31860	6456
85	6418	736	1371	795	220	44	350	159	307	10400	31860	6455
86	6419	736	1371	795	220	44	349	159	307	10400	31860	6455
87	6420	734	1370	795	220	44	349	161	307	10400	31860	6453
88	6420	733	1370	796	220	44	349	161	307	10400	31871	6452
89	6421	731	1365	797	220	44	350	163	309	10400	31862	6444
90	6422	730	1361	798	220	44	351	162	313	10400	31860	6437
91	6422	730	1361	798	220	44	351	162	313	10400	31861	6437
92	6422	729	1360	798	220	44	351	162	313	10400	31861	6436

93	6423	728	1359	798	220	44	349	163	316	10400	31861	6432
94	6425	727	1358	799	220	44	346	163	318	10400	31862	6430
95	6427	727	1357	799	220	44	344	163	319	10400	31862	6430
96	6427	725	1357	799	220	44	344	164	320	10400	31860	6427
97	6427	723	1357	799	220	44	345	165	320	10400	31860	6426
98	6429	721	1356	799	220	44	344	166	320	10400	31860	6424
99	6429	720	1354	800	220	44	343	168	321	10400	31860	6420
100	6431	717	1354	800	220	44	342	169	323	10400	31861	6417
101	6431	717	1353	800	220	44	342	169	324	10400	31861	6415
102	6431	716	1353	800	220	44	342	169	325	10400	31860	6414
103	6432	716	1352	800	220	44	340	169	326	10400	31860	6413
104	6432	716	1351	800	220	44	341	170	326	10400	31861	6412
105	6433	714	1350	802	220	44	341	171	326	10400	31871	6409
106	6433	714	1348	801	220	44	342	171	327	10400	31861	6407
107	6433	714	1348	801	220	44	342	171	327	10400	31860	6406
108	6434	711	1343	804	220	44	344	172	329	10400	31867	6398
109	6436	711	1342	803	220	44	344	171	329	10400	31861	6397
110	6437	710	1339	804	220	44	342	172	331	10400	31864	6393
111	6437	710	1336	805	220	44	342	173	332	10400	31871	6389
112	6438	707	1334	806	220	44	342	176	333	10400	31870	6384
113	6440	706	1330	807	220	44	342	177	333	10400	31868	6378
114	6440	707	1328	807	220	44	343	178	333	10400	31863	6376
115	6440	706	1327	808	220	44	343	178	333	10400	31869	6374
116	6442	705	1325	808	220	44	344	179	333	10400	31860	6369
117	6442	703	1322	809	220	44	344	181	333	10400	31868	6366
118	6443	703	1322	809	220	44	345	181	333	10400	31860	6365
119	6443	702	1322	809	220	44	345	181	333	10400	31860	6364
120	6447	700	1319	810	221	44	344	182	333	10400	31865	6360
121	6448	700	1318	810	220	44	344	182	333	10400	31860	6358
122	6447	700	1318	810	220	44	344	183	333	10400	31860	6358
123	6449	697	1317	811	220	44	345	183	333	10400	31861	6354
124	6450	697	1315	812	220	44	346	183	333	10400	31860	6351
125	6450	696	1314	812	220	44	346	183	333	10400	31860	6350
126	6451	694	1314	812	220	44	346	186	333	10400	31860	6348
127	6451	693	1314	812	220	44	346	186	333	10400	31860	6347
128	6451	693	1313	812	220	44	346	186	333	10400	31860	6346
129	6452	692	1313	812	220	44	346	187	333	10400	31860	6345
130	6453	691	1312	813	220	44	345	188	333	10400	31870	6344
131	6453	690	1309	814	220	44	347	189	333	10400	31869	6339
132	6454	690	1306	814	220	44	348	190	333	10400	31860	6335
133	6454	688	1306	815	220	44	348	190	333	10400	31862	6334
134	6456	688	1306	815	220	44	348	190	333	10400	31860	6333
135	6457	688	1305	815	220	44	347	191	333	10400	31860	6332
136	6458	687	1305	815	220	44	346	192	333	10400	31860	6331
137	6459	685	1304	815	220	44	346	193	333	10400	31861	6328
138	6460	683	1302	816	220	44	346	194	333	10400	31868	6324
139	6461	683	1300	817	220	44	348	194	333	10400	31861	6321
140	6463	680	1298	818	220	44	348	196	333	10400	31870	6318
141	6466	680	1297	818	220	44	346	196	333	10400	31861	6315
142	6466	679	1296	819	220	44	346	196	333	10400	31871	6314
143	6466	679	1295	818	220	44	347	197	333	10400	31860	6311
144	6466	679	1294	818	220	44	347	198	333	10400	31860	6311
145	6468	679	1292	819	220	44	346	199	333	10400	31866	6308
146	6468	678	1291	819	220	44	347	199	333	10400	31860	6306
147	6469	677	1289	820	220	44	347	200	333	10400	31863	6303
148	6471	675	1288	820	220	44	347	201	333	10400	31860	6300
149	6472	675	1287	821	220	44	349	198	333	10400	31860	6299
150	6473	675	1287	821	220	44	349	198	333	10400	31860	6299
151	6473	674	1287	821	220	44	348	199	333	10400	31860	6298
152	6474	674	1287	821	220	44	348	199	333	10400	31860	6297
153	6475	673	1287	821	220	44	347	199	333	10400	31860	6297
154	6477	673	1284	822	220	44	347	200	333	10400	31861	6293
155	6477	673	1284	822	220	44	347	200	333	10400	31860	6293
156	6477	673	1284	822	220	44	347	200	333	10400	31860	6292
157	6478	673	1283	822	220	44	347	200	333	10400	31860	6292
158	6479	672	1282	823	220	44	346	200	333	10400	31861	6290
159	6480	671	1280	823	220	44	346	202	333	10400	31861	6287
160	6481	671	1279	824	220	44	346	202	333	10400	31871	6286
161	6481	670	1278	824	220	44	346	203	333	10400	31870	6284
162	6484	668	1277	824	220	44	345	204	333	10400	31860	6281
163	6484	668	1277	824	220	44	345	204	333	10400	31860	6280
164	6484	668	1276	824	220	44	346	205	333	10400	31860	6278
165	6487	667	1272	826	220	44	344	207	333	10400	31862	6274
166	6487	667	1271	826	220	44	345	207	333	10400	31860	6272
167	6490	666	1270	826	220	44	345	206	333	10400	31861	6270
168	6491	665	1270	826	220	44	344	207	333	10400	31860	6268
169	6491	665	1269	827	220	44	344	207	333	10400	31860	6268
170	6492	664	1269	827	220	44	344	207	333	10400	31860	6267
171	6494	664	1267	828	220	44	343	206	333	10400	31870	6265
172	6495	663	1266	828	220	44	343	207	333	10400	31860	6263
173	6496	664	1263	829	220	44	343	207	333	10400	31862	6260
174	6497	665	1260	829	220	44	344	207	333	10400	31861	6257
175	6497	665	1260	829	220	44	344	207	333	10400	31860	6256
176	6497	665	1260	830	220	44	344	207	333	10400	31860	6256
177	6497	665	1260	830	220	44	344	207	333	10400	31861	6255
178	6500	663	1259	830	220	44	342	208	333	10400	31861	6254
179	6502	662	1256	831	220	44	341	210	333	10400	31862	6249
180	6502	661	1255	831	220	44	342	211	333	10400	31864	6247
181	6503	661	1254	831	220	44	342	211	333	10400	31860	6245
182	6504	660	1253	832	220	44	342	212	333	10400	31860	6244
183	6505	660	1253	832	220	44	341	212	333	10400	31860	6243
184	6507	658	1250	833	220	44	341	214	333	10400	31864	6238
185	6507	657	1249	833	220	44	342	215	333	10400	31860	6236
186	6508	657	1249	833	220	44	340	216	333	10400	31860	6235
187	6509	656	1248	833	220	44	341	216	333	10400	31860	6233
188	6510	655	1246	834	220	44	341	217	333	10400	31860	6230
189	6510	655	1246	834	220	44	341	217	333	10400	31860	6230

190	6510	655	1246	834	220	44	341	217	333	10400	31860	6230
191	6510	655	1245	834	220	44	341	217	333	10400	31860	6230
192	6510	654	1244	835	220	44	342	217	333	10400	31870	6228
193	6512	654	1243	835	220	44	342	217	333	10400	31860	6226
194	6512	653	1241	835	220	44	343	217	333	10400	31860	6223
195	6513	653	1241	835	220	44	343	217	333	10400	31860	6222

APPENDIX B

TRIP GENERATION DATA FROM ENVIRONMENTAL REVIEWS

Figure B.1 Domino Sugar Travel Demand Characteristics.

Table 17-11
Proposed Project
Trip Generation Factors

Factors	Residential 2,400 dwelling unit (d.u.)				Community Facility Medical Office - Staff 69,000 s.f.				Community Facility Medical Office - Visitors 69,000 s.f.				Community Facility Office 44,135 s.f.				Commercial Office 98,738 s.f.			
	AM	MD	PM	Sat MD	AM	MD	PM	Sat MD	AM	MD	PM	Sat MD	AM	MD	PM	Sat MD	AM	MD	PM	Sat MD
		Daily Trip Rate (per d.u.) [1,2]				Daily Trip Rate (per 1,000 sf) [8,9]				Daily Trip Rate (per 1,000 sf) [8,8]				Daily Trip Rate (per 1,000 sf) [1,2]				Daily Trip Rate (per 1,000 sf) [1,2]		
Person Trips		8.075		7.679		10.00		4.30		33.6		14.5		18.0		0.9		18.0		0.9
Linkage (if applicable)		-				-				-				-				-		
		Modal Split[4,5]				Modal Split[2,11]				Modal Split[8]				Modal Split[2,11]				Modal Split[2,11]		
Auto		16.2%		23.1%	49.2%	2.0%	49.2%	2.0%		25.0%			49.2%	2.0%	49.2%	2.0%	49.2%	2.0%	49.2%	2.0%
Bus		10.1%		10.1%	6.7%	7.0%	6.7%	7.0%		19.0%			6.7%	7.0%	6.7%	7.0%	6.7%	7.0%	6.7%	7.0%
Subway		52.9%		33.1%	28.1%	7.0%	28.1%	7.0%		21.0%			28.1%	7.0%	28.1%	7.0%	28.1%	7.0%	28.1%	7.0%
Walk/Other		19.0%		31.9%	14.1%	83.0%	14.1%	83.0%		20.0%			14.1%	83.0%	14.1%	83.0%	14.1%	83.0%	14.1%	83.0%
Taxi		1.8%		1.8%	1.9%	1.0%	1.9%	1.0%		15.0%			1.9%	1.0%	1.9%	1.0%	1.9%	1.0%	1.9%	1.0%
		Vehicle Occupancies[4,6]				Vehicle Occupancies[2,11]				Vehicle Occupancies[8]				Vehicle Occupancies[2,11]				Vehicle Occupancies[2,11]		
Auto Occupancy		1.28				1.17				1.65				1.17				1.17		
Taxi Occupancy		1.50				1.42				1.20				1.42				1.42		
		Temporal Distribution[1,2]				Temporal Distribution[8,9]				Temporal Distribution[8,13]				Temporal Distribution[2]				Temporal Distribution[2]		
	9.1%	4.7%	10.7%	7.0%	24.0%	17.0%	24.0%	17.0%	6.0%	9.0%	5.0%	9.0%	11.8%	14.5%	13.7%	15.0%	11.8%	14.5%	13.7%	15.0%
		Directional Distribution[2,7]				Directional Distribution[8,10]				Directional Distribution[8,13]				Directional Distribution[2,14]				Directional Distribution[2,14]		
Percent In	15%	50%	70%	50%	100%	50%	0%	50%	92.5%	50.0%	31.4%	50.0%	94.0%	39.0%	5.0%	60.0%	94.0%	39.0%	5.0%	60.0%
Percent Out	85%	50%	30%	50%	0%	50%	100%	50%	7.5%	50.0%	68.6%	50.0%	6.0%	61.0%	95.0%	40.0%	6.0%	61.0%	95.0%	40.0%
Delivery Trips																				
		Daily Trip Rate (per d.u.) [1,2]				Daily Trip Rate (per 1,000 sf) [8]				Daily Trip Rate				Daily Trip Rate (per 1,000 sf) [2]				Daily Trip Rate (per 1,000 sf) [2]		
Truck Trips		0.05		0.01		0.45		0.00	-	-	-	-		0.16		0.01		0.16		0.01
		Temporal Distribution[2,3]				Temporal Distribution[8,12]				Temporal Distribution				Temporal Distribution[2,14]				Temporal Distribution[2,14]		
	9.7%	7.8%	5.1%	9.0%	9.7%	7.8%	5.1%	0.0%	-	-	-	-	10.0%	11.0%	2.0%	11.0%	10.0%	11.0%	2.0%	11.0%
		Direction Distribution[2,3]				Direction Distribution[8,12]				Direction Distribution				Direction Distribution[2,14]				Direction Distribution[2,14]		
Percent In	100%	100%	100%	100%	100%	100%	100%	0%	-	-	-	-	100%	100%	100%	100%	100%	100%	100%	100%
Percent Out	100%	100%	100%	100%	100%	100%	100%	0%	-	-	-	-	100%	100%	100%	100%	100%	100%	100%	100%

Factors	Retail - Local 97,537 s.f.				Retail - Supermarket 30,000 s.f.				Open Space Ice Rink/Water Play Area 9,042 s.f.				Open Space Other 3.85 acres				Community Facility Museum 33,316 s.f.			
	AM	MD	PM	Sat MD	AM	MD	PM	Sat MD	AM	MD	PM	Sat MD	AM	MD	PM	Sat MD	AM	MD	PM	Sat MD
		Daily Trip Rate (per 1,000 sf) [1,2]				Daily Trip Rate (per 1,000 sf) [16]				Daily Trip Rate (per 1,000 sf) [17]				Daily Trip Rate (per acre) [18]				Daily Trip Rate (per 1,000 sf) [19]		
Person Trips		205.00				175.00		231.00		23.50		33.30		139.00				27.40		20.60
Linkage (if applicable)		25%				25%				-				-				-		
		Modal Split[15]				Modal Split[16]				Modal Split[17]				Modal Split[18]				Modal Split[20]		
Auto		5.0%			61.0%	68.0%	67.0%	76.0%	58.0%	58.0%	58.0%	64.0%	5.0%	5.0%	5.0%	5.0%		70.0%		
Bus		5.0%			5.0%	5.0%	3.0%	6.0%	0.0%	0.0%	0.0%	3.0%	5.0%	5.0%	5.0%	5.0%		5.0%		
Subway		5.0%			1.0%	0.0%	0.0%	0.0%	11.0%	11.0%	11.0%	15.0%	5.0%	5.0%	5.0%	5.0%		10.0%		
Walk/Other		80.0%			33.0%	27.0%	30.0%	18.0%	29.0%	29.0%	29.0%	14.0%	80.0%	80.0%	80.0%	80.0%		10.0%		
Taxi		5.0%			0.0%	0.0%	0.0%	0.0%	2.0%	2.0%	2.0%	4.0%	5.0%	5.0%	5.0%	5.0%		5.0%		
		Vehicle Occupancies[15]				Vehicle Occupancies[16]				Vehicle Occupancies[17]				Vehicle Occupancies[18]				Vehicle Occupancies[19]		
Auto Occupancy		2.20		2.1	1.12	1.32	1.34	1.48		3.45				2.00				2.34		
Taxi Occupancy		2.20		2.1	1.38	1.38	1.38	1.38		1.40				2.00				1.90		
		Temporal Distribution[2,15]				Temporal Distribution[16]				Temporal Distribution[17]				Temporal Distribution[18]				Temporal Distribution[19]		
	3.1%	10.1%	8.6%	9.5%	4.7%	5.9%	9.9%	9.3%	0.0%	28.0%	16.0%	24.0%	7.0%	17.0%	14.0%	17.0%	0.0%	7.2%	14.4%	16.8%
		Directional Distribution[2,15]				Directional Distribution[16]				Directional Distribution[17]				Directional Distribution[18]				Directional Distribution[19]		
Percent In	50.0%	47.0%	44.0%	55.0%	57.0%	50.0%	52.0%	52.0%	0.0%	26.0%	88.0%	99.0%	50.0%	50.0%	50.0%	50.0%	50.0%	63.0%	52.0%	36.0%
Percent Out	50.0%	53.0%	56.0%	45.0%	43.0%	50.0%	48.0%	48.0%	0.0%	74.0%	12.0%	1.0%	50.0%	50.0%	50.0%	50.0%	50.0%	37.0%	48.0%	64.0%
Delivery Trips																				
		Daily Trip Rate (per 1,000 sf) [2]				Daily Trip Rate (per 1,000 sf) [16]				Daily Trip Rate				Daily Trip Rate				Daily Trip Rate (per 1,000 sf) [19]		
Truck Trips		0.35		0.02		2.14		0.85	-	-	-	-	-	-	-	-		0.05		0.00
		Temporal Distribution[2,3]				Temporal Distribution[16]				Temporal Distribution				Temporal Distribution				Temporal Distribution[19]		
	9.7%	7.8%	5.1%	11.0%	12.0%	13.0%	4.0%	9.0%	-	-	-	-	-	-	-	-	9.6%	11.0%	1.0%	1.0%
		Direction Distribution[2,3]				Direction Distribution[16]				Direction Distribution				Direction Distribution				Direction Distribution[19]		
Percent In	100%	100%	100%	100%	50%	36%	67%	67%	-	-	-	-	-	-	-	-	100%	100%	100%	100%
Percent Out	100%	100%	100%	100%	50%	64%	33%	33%	-	-	-	-	-	-	-	-	100%	100%	100%	100%

Notes:
(01) Source: New York City Mayor's Office of Environmental Coordination *City Environmental Quality Review Technical Manual* (December 2001)
(02) Source: *Atlantic Yards Arena and Redevelopment Project, Final Environmental Impact Statement*(2006)
(03) Source: Wilbur Smith Associates, *Motor Trucks in the Metropolis* (1969)
(04) Source: Journey to Work information for Census Tract # 547, 549, 551, and 555 from 2000 U.S. Census Data
(05) Saturday modal split estimates based on Journey to Work information for Census Tract # 547, 549, 551, and 555 from 2000 U.S. Census Data and adjusted as per the information provided in *Atlantic Yards Arena and Redevelopment Project, FEIS* (2006)
(06) Source: *Flushing/Bedford Rezoning Final Environmental Impact Statement*(CEQR No. 00DCP015K), 2001
(07) Source: Pushkarev & Zapan, *Urban Space for Pedestrians* (1975)
(08) Source: *506 East 76th Street Rezoning FEIS* (CEQR No. 98DCP009M), October 1999
(09) Source: *Jamaica Plan FEIS*, June 2007
(10) Saturday directional distribution assumed same as weekday midday
(11) Source: Reverse Journey to Work information for Census Tract # 547, 549, 551, and 555 from 2000 U.S. Census Data
(12) Source: Characteristics of Urban Transportation Demand
(13) Saturday temporal distribution and direction distribution assumed the same as weekday midday
(14) Source: *Downtown Brooklyn FEIS* (CEQR No. 03DME016K), April 2004
(15) Source: New York City Department of City Planning, *Retail and Industrial Zoning Text Amendments: Final Generic Environmental Impact Statement*(1996) - Gowanus, Brooklyn
(16) Source: Supermarket survey at Pathmark (Albany Avenue, Brooklyn) by AKRF, 2009
(17) Source: McCarren Park Pool EAS (2008)
(18) Source: *Toll Brothers - Gowanus Rezoning FEIS* (February 2009)
(19) Source: *No. 7 Subway Extension and Hudson Yards Rezoning and Development Program FGEIS*(2004)
(20) Source: *Silvercup West FEIS*, CEQR # 05DCP080Q (2006)

Figure B.2 E. 126th St. Memorial and Mixed-Use Project Travel Demand Characteristics.

Table 1: Transportation Planning Factors – RWCDS

Land Use:	Office		Destination Retail		Residential		Local Retail		Community Facility		Museum	
Size/Units:	200,000	gsf	80,000	gsf	730 DU		35,000	gsf	15,000	gsf	15,000	gsf
Trip Generation:	(1)		(1)		(1)		(1)		(3)		(3)	
Weekday	18.0		78.2		8.075		205.0		44.7		27.0	
Saturday	3.0		92.5		9.600		240.0		26.1		20.6	
	per 1,000 gsf		per 1,000 gsf		per DU		per 1,000 gsf		per 1,000 gsf		per 1,000 gsf	
Temporal Distribution:	(1)		(1)		(1)		(1)		(1)		(3)	
AM	12.0%		3.0%		10.0%		3.0%		4.0%		1.0%	
MD	15.0%		9.0%		5.0%		19.0%		9.0%		16.0%	
PM	14.0%		9.0%		11.0%		10.0%		5.0%		13.0%	
SatMD	17.0%		11.0%		8.0%		10.0%		9.0%		7.0%	
	(2)		(2)		(4)		(5)		(3)		(3)	
Modal Splits:	AM/PM	MD/SAT	Weekday	Saturday	All Periods		All Periods		All Periods		Weekday	Saturday
Auto	12.0%	2.0%	15.0%	17.0%	14.0%		7.3%		4.0%		12.0%	14.0%
Taxi	1.0%	1.0%	9.0%	10.0%	1.0%		1.7%		9.0%		10.0%	10.0%
Subway	68.0%	7.0%	26.0%	15.0%	57.0%		2.7%		12.0%		7.0%	7.0%
Bus	12.0%	7.0%	12.0%	20.0%	14.0%		8.7%		5.0%		29.0%	29.0%
Railroad	1.0%	0.0%	1.0%	1.0%	2.0%		1.0%		0.0%		0.0%	0.0%
Walk/Other	6.0%	83.0%	37.0%	37.0%	12.0%		78.6%		70.0%		42.0%	40.0%
	100.0%	100.0%	100.0%	100.0%	100.0%		100.0%		100.0%		100.0%	100.0%
	(3)		(2)		(3)		(3)		(3)		(3)	
In/Out Splits:	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
AM	95%	5%	61%	39%	16.0%	84.0%	50%	50%	61%	39%	50%	50%
MD	48%	52%	55%	45%	50.0%	50.0%	50%	50%	55%	45%	63%	37%
PM	15%	85%	47%	53%	67.0%	33.0%	50%	50%	29%	71%	52%	48%
Sat MD	60%	40%	55%	45%	53.0%	47.0%	50%	50%	49%	51%	63%	37%
Vehicle Occupancy:	(2)		(2)		(3,4)		(3)		(3)		(3)	
	All Periods		Weekday	Saturday	All Periods		All Periods		All Periods		All Periods	
Auto	1.09		2.00	2.70	1.18		2.00		1.40		2.34	
Taxi	1.40		2.00	2.80	1.4		2.00		1.40		1.90	
Truck Trip Generation:	(1)		(2)		(1)		(1)		(3)		(3)	
Weekday	0.32		0.35		0.06		0.35		0.04		0.05	
Saturday	0.01		0.04		0.02		0.04		0.01		0.01	
	per 1,000 sf		per 1,000 sf		per DU		per 1,000 sf		per 1,000 sf		per 1,000 sf	
	(1)		(2)		(1)		(1)		(3)		(3)	
AM	10.0%		7.7%		12.0%		8.0%		7.7%		9.6%	
MD	11.0%		11.0%		9.0%		11.0%		11.0%		11.0%	
PM	2.0%		1.0%		2.0%		2.0%		2.0%		1.0%	
Sat MD	11.0%		11.0%		9.0%		11.0%		11.0%		11.0%	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
AM/MD/PM	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%

Notes :

(1) Based on 2014 *City Environmental Quality Review (CEQR) Technical Manual.* Health club rates assumed for community facility temporal distribution.
(2) Based on the *East 125th Street Development FEIS*, 2008.
(3) Based on *West Harlem Rezoning FEIS*, 2012.
(4) Based on 2010-2014 *American Community Survey (ACS)* Means of Transportation to Work Table for Manhattan Census Tracts 192, 194, 196, and 242.
(5) Based on 2015 NYCDOT Trip Generation and Mode Choice Survey.

Figure B.3 Gateway Estates II Travel Demand Characteristics.

Table 16-30
2013 Build Travel Demand Factors (Weekday)

	Residential	Destination Retail	Local Retail	High School		Day Care	Community Facility	Open Space
				Students	Faculty			
Person Trip Generation Rate	12.5[1] per DU	1.55 - AM[5] 5.03 - Midday[5] 4.89 - PM[5] per 1,000 SF	205[4] per 1,000 SF	1.8[6] per seat	1.99[6] per staff	138[10] per 1,000 SF	40[1] per 1,000 SF	193[1] per 1,000 SF
Temporal Distribution								
AM Peak	9.1%[2]	NA[5]	2.3%[1]	45.0%[6]	45.0%[6]	16.0%[10]	5.0%[1]	7.0%[2]
Midday Peak	4.7%[2]	NA[5]	7.9%[1]	2.0%[1]	0.0%[9]	5.0%[10]	10.0%[1]	17.0%[2]
PM Peak	10.7%[2]	NA[5]	10.7%[1]	8.2%[7]	8.2%[1]	19.0%[10]	10.0%[1]	14.0%[2]
Linked Trip Credit	0.0%	25.0%	25.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Modal Split								
Auto	48.0%[3]	95.1%[5]	15.0%[1]	35.0%[6]	95.0%[6]	48.0%[11]	4.0%[1]	12.0%[1]
Taxi	3.0%[3]	1.5%[5]	0.0%[1]	0.0%[6]	0.0%[6]	3.0%[11]	7.0%[1]	0.0%[1]
Subway/Bus	30.0%[3]	1.2%[5]	0.0%[1]	10.0%[6]	0.0%[6]	30.0%[11]	0.0%[1]	5.0%[1]
Bus Only	13.0%[3]	1.2%[5]	5.0%[1]	40.0%[6]	5.0%[6]	13.0%[11]	14.0%[1]	5.0%[1]
Walk Only	6.0%[3]	1.0%[5]	80.0%[1]	15.0%[6]	0.0%[6]	6.0%[11]	75.0%[1]	78.0%[1]
Vehicle Occupancy								
Auto	1.15[3]	1.40[5]	1.40[5]	1.50[6]	1.20[6]	2.00[9]	2.00[1]	2.80[1]
Taxi	1.15[3]	1.65[5]	1.65[5]	1.50[6]	1.20[6]	2.00[9]	2.00[1]	2.00[1]
Directional Split (Ins)								
AM Peak	15.0%[2]	62.5%[5]	63.0%[1]	100.0%[6]	100.0%[6]	53.0%[10]	70.0%[1]	80.0%[1]
Midday Peak	50.0%[2]	53.6%[5]	55.0%[1]	2.0%[1]	0.0%[1]	50.0%[10]	50.0%[1]	55.0%[1]
PM Peak	70.0%[2]	51.8%[5]	47.0%[1]	0.0%[7]	0.0%[1]	47.0%[10]	50.0%[1]	45.0%[1]
Truck Trip Generation Rate	0.06[2] per DU	0.35[1] per 1,000 SF	0.35[1] per 1,000 SF	0.064[1] per seat		0.07[10] per 1,000 SF	0.02[1] per 1,000 SF	-
Truck Temporal Distribution								
AM Peak	6.0%[4]	13.0%[1]	6.0%[1]	9.7%[8]		9.7%[10]	6.0%[1]	-
Midday Peak	7.0%[4]	9.0%[1]	11.0%[1]	7.8%[8]		7.8%[10]	11.0%[1]	-
PM Peak	10.0%[4]	0.0%[1]	0.0%[1]	5.1%[8]		5.1%[10]	1.0%[9]	-
Truck Trip Directional Split (Ins)								
AM Peak	50.0%	50.0%	50.0%	50.0%		50.0%	50.0%	-
Midday Peak	50.0%	50.0%	50.0%	50.0%		50.0%	50.0%	-
PM Peak	50.0%	50.0%	50.0%	50.0%		50.0%	50.0%	-

Notes:

1. *Gateway Estates FEIS* (1996)
2. *Greenpoint-Williamsburg Rezoning FEIS* (2005)
3. *Census 2000* (U.S. Department of Commerce: Bureau of the Census, 2000)
4. *Urban Space for Pedestrians*, Pushkarev and Zupan, 1973
5. Surveys conducted by AKRF, Inc. at Gateway Center (November 2006). Note: temporal distribution not included (for destination retail) since rates are specific to individual peak hours.
6. *Sunset Park High School Facility FEIS* (2005) – modal split slightly adjusted to reflect local conditions
7. *Trip Generation, 7th Edition* (Institute of Transportation Engineers, 2003)
8. *Curbside Pickup and Delivery Operations and Arterial Traffic Impacts*, U.S. Department of Transportation/Federal Highway Administration (1981)
9. Project team assumption
10. *No. 7 Subway Extension—Hudson Yards Rezoning and Development Program FGEIS* (2004)
11. Assumed similar to Residential

Figure B.4 Inwood Rezoning Travel Demand Characteristics.

TABLE 2: Transportation Planning Factors

Land Use:	Local Retail		Office		Residential		Auto Repair/ Related		FRESH Supermarket		Community Center		House of Worship		Medical Office (Staff)		Medical Office (Visitors)	
Size/Units:	264,794 gsf		488,168 gsf		4,348 DU		-25,609 gsf		26,958 gsf		95,446 gsf		9,991 gsf		274,436 gsf		274,436 gsf	
Trip Generation:	(1)		(1)		(1)		(7)		(8,9)		(1)		(12,13)		(11,14)		(11,14)	
Weekday	205.0		18.0		8.075		19.42		205.0		44.7		13.4		10.0		33.6	
Saturday	240.0		3.9		9.600		19.42		271.0		26.1		54.0		4.3		14.5	
	per 1,000 sf		per 1,000 sf		per DU		per 1,000 sf		per 1,000 sf		per 1,000 sf		per 1,000 sf		per 1,000 sf		per 1,000 sf	
Link Trip Rate Percentage	25%		0%		0%		0%		0%		0%		0%		0%		0%	
Temporal Distribution:	(1)		(1)		(1)		(7)		(8,10)		(1)		(12,13)		(11,14)		(11,14)	
AM	3.0%		12.0%		10.0%		13.2%		3.0%		4.0%		7.9%		24.0%		6.0%	
MD	19.0%		15.0%		5.0%		11.0%		12.0%		9.0%		14.1%		17.0%		9.0%	
PM	10.0%		14.0%		11.0%		14.2%		10.0%		5.0%		7.2%		24.0%		5.0%	
SAT	10.0%		17.0%		8.0%		10.7%		12.0%		9.0%		5.2%		17.0%		9.0%	
	(19)		(3)	(4)	(5)		(7)		(8)		(2)		(12,13)		(17)		(14)	
Modal Splits:	AM/MD/PM	SAT	AM/PM/SAT	MD	All Periods		All Periods		All Periods		All Periods		All Periods		AM/PM/SAT	MD	All Periods	
Auto	2.5%	7.0%	28.4%	2.0%	15.3%		85.0%		4.0%		4.0%		4.0%		28.4%	2.0%	25.0%	
Taxi	0.5%	0.0%	1.7%	3.0%	1.0%		5.0%		3.0%		9.0%		9.0%		1.7%	3.0%	25.0%	
Subway/Railroad	16.5%	21.0%	39.0%	6.0%	64.6%		1.0%		5.0%		12.0%		12.0%		39.0%	6.0%	29.0%	
Bus	4.0%	9.0%	13.7%	6.0%	7.9%		1.0%		5.0%		5.0%		5.0%		13.7%	6.0%	11.0%	
School Bus	0.0%	0.0%	0.0%	0.0%	0.0%		0.0%		0.0%		0.0%		0.0%		0.0%	0.0%	0.0%	
Walk/Other	76.5%	63.0%	17.2%	83.0%	11.2%		8.0%		83.0%		70.0%		70.0%		17.2%	83.0%	10.0%	
	100.0%	100.0%	100.0%	100.0%	100.0%		100.0%		100.0%		100.0%		100.0%		100.0%	100.0%	100.0%	
	(2)		(2)		(2)		(7)		(8,10)		(2)		(12,13)		(11,14)		(11,14)	
In/Out Splits:	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
AM	50%	50%	95.0%	5.0%	16.0%	84.0%	65%	35%	45%	55%	66%	34%	54%	46%	100%	0%	90%	10%
MD	50%	50%	48.0%	52.0%	50.0%	50.0%	50%	50%	46%	54%	58%	42%	54%	46%	50%	50%	50%	50%
PM	50%	50%	15.0%	85.0%	67.0%	33.0%	50%	50%	47%	53%	34%	66%	54%	46%	0%	100%	30%	70%
SAT	50%	50%	60.0%	40.0%	53.0%	47.0%	50%	50%	46%	54%	58%	42%	100%	0%	50%	50%	50%	50%
					(2,5,6)													
Vehicle Occupancy:	(2)		(2,3)		AM/PM	MD/SAT	(7)		(8,10)		(2)		(12,13)		(3,14)		(14)	
Auto	2.00		1.12		1.24	1.74	1.30		1.65		1.40		1.40		1.12		1.65	
Taxi	2.00		1.40		1.40	1.96	1.30		1.40		1.40		1.40		1.40		1.20	
School Bus																		
Truck Trip Generation:	(1)		(1)		(1)		(7)		(8,10)		(2)		(12,13)		(11,14)			
Weekday	0.35		0.32		0.06		0.89		0.35		0.04		0.15		0.40		N/A	
Saturday	0.04		0.01		0.02		0.89		0.04		0.01		0.01		0.00		N/A	
	per 1,000 sf		per 1,000 sf		per DU		per 1,000 sf		per 1,000 sf		per 1,000 sf		per 1,000 sf		per 1,000 sf			
	(1)		(1)		(1)		(7)		(8,10)		(2)		(12,13)		(11,14)			
AM	8.0%		10.0%		12.0%		14.0%		10.0%		7.7%		9.6%		9.7%		N/A	
MD	11.0%		11.0%		9.0%		9.0%		8.0%		11.0%		11.0%		7.8%		N/A	
PM	2.0%		2.0%		2.0%		1.0%		5.0%		2.0%		1.0%		5.1%		N/A	
SAT	11.0%		11.0%		9.0%		0.0%		10.0%		11.0%		1.0%		0.0%		N/A	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
AM/MD/PM/SAT	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%

Figure B.5 Inwood Rezoning Travel Demand Characteristics Continued.

TABLE 2: Transportation Planning Factors (continued)

Land Use:	Pre-K - Grade 4 Students		Grade 5-7 Students		Grade 8 Students		School Staff		Parents (Pre-K - Grade 5)		Public Library		Light Industrial		Destination Retail	
Size/Units:	411 Students		128 Students		36 Students		55 Staff		87 Parents		666 gsf		-59,059 gsf		104,376 gsf	
Trip Generation:	(4)		(4)		(4)		(4)		(4)		(20)		(7)		(1)	
Weekday	2.0		2.0		2.0		2.0		4.0		97.7		14.7		78.2	
Saturday	0.0		0.0		0.0		0.0		0.0		80.9		2.2		92.5	
	per Student		per Student		per Student		per Staff		per Student		per 1,000 sf		per 1,000 sf		per 1,000 sf	
Link Trip Rate Percentage	0%		0%		0%		0%		0%		0%		0%		0%	
Temporal Distribution:	(4)		(4)		(4)		(4)		(4)		(20,22)		(7)		(1)	
AM	50.0%		50.0%		50.0%		50.0%		50.0%		7.9%		13.2%		3.0%	
MD	0.0%		0.0%		0.0%		0.0%		0.0%		14.5%		11.0%		9.0%	
PM	5.0%		5.0%		5.0%		50.0%		5.0%		12.8%		14.2%		9.0%	
SAT	0.0%		0.0%		0.0%		0.0%		0.0%		14.5%		10.7%		11.0%	
	(4)		(4)		(4)		(17)		(4)		(21)		(17)		(23)	
Modal Splits:	AM/MD/SAT	PM	AM/MD/SAT	PM	All Periods		AM/PM/SAT	MD	All Periods		All Periods		AM/PM/SAT	MD	AM/MD/PM	SAT
Auto	15.0%	56.3%	15.0%	30.0%	15.0%		28.4%	2.0%	0.0%		5.0%		28.4%	2.0%	15.0%	17.0%
Taxi	0.0%	0.0%	0.0%	0.0%	0.0%		1.7%	3.0%	0.0%		1.0%		1.7%	3.0%	9.0%	10.0%
Subway/Railroad	3.3%	12.4%	6.7%	13.4%	40.0%		39.0%	6.0%	0.0%		3.0%		39.0%	6.0%	27.0%	16.0%
Bus	1.7%	6.4%	3.3%	6.6%	20.0%		13.7%	6.0%	0.0%		6.0%		13.7%	6.0%	12.0%	20.0%
School Bus	55.0%	0.0%	25.0%	0.0%	0.0%		0.0%	0.0%	0.0%		0.0%		0.0%	0.0%	0.0%	0.0%
Walk/Other	25.0%	25.0%	50.0%	50.0%	25.0%		17.2%	83.0%	100.0%		85.0%		17.2%	83.0%	37.0%	37.0%
	100.0%	100.0%	100.0%	100.0%	100.0%		100.0%	100.0%	100.0%		100.0%		100.0%	100.0%	100.0%	100.0%
	(4)		(4)		(4)		(4)		(4)		(20,22)		(7)		(23)	
In/Out Splits:	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
AM	100%	0%	100%	0%	100%	0%	100%	0%	50%	50%	71%	29%	95.0%	5.0%	61%	39%
MD	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	53%	47%	48.0%	52.0%	55%	45%
PM	0%	100%	0%	100%	0%	100%	0%	100%	50%	50%	48%	52%	15.0%	85.0%	47%	53%
SAT	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	53%	47%	60.0%	40.0%	55%	45%
															(23)	
Vehicle Occupancy:	(4)		(4)		(4)		(18)				(21)		(7)		AM/MD/PM	SAT
Auto	1.30		1.30		1.30		1.12		N/A		1.65		1.12		2.00	2.70
Taxi	1.30		1.30		1.30		1.40		N/A		1.30		1.40		2.00	2.80
School Bus	35.00		35.00		35.00											
Truck Trip Generation:	(4)		(4)		(4)						(21)		(7)		(23)	
Weekday	0.03		0.03		0.03		N/A		N/A		0.29		0.67		0.35	
Saturday	0.03		0.03		0.03		N/A		N/A		0.29		0.67		0.02	
	per Student		per Student		per Student						per 1,000 sf		per 1,000 sf		per 1,000 sf	
	(4)		(4)		(4)						(21)		(7)		(23)	
AM	9.6%		9.6%		9.6%		N/A		N/A		9.6%		14.0%		7.7%	
MD	11.0%		11.0%		11.0%		N/A		N/A		11.0%		9.0%		11.0%	
PM	1.0%		1.0%		1.0%		N/A		N/A		1.0%		1.0%		1.0%	
SAT	0.0%		0.0%		0.0%		N/A		N/A		0.0%		0.0%		11.0%	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
AM/MD/PM/SAT	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	N/A	N/A	N/A	N/A	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%

Figure B.6 Inwood Rezoning Travel Demand Characteristics Continued.

TABLE 2: Transportation Planning Factors (continued)

Notes:

(1) Based on data from *City Environmental Quality Review (CEQR) Technical Manual*, 2014. Health club rates assumed for community center trip generation and temporal distributions rates.

(2) Based on data from *West Harlem Rezoning FEIS, 2012*

(3) Based on AASHTO CTPP Reverse Journey to Work 5-Year data for Manhattan Census Tracts 283, 285, 287, 291, 293, 295, 299, 303 and 307.

(4) Based on data from *East New York Rezoning Proposal FEIS, 2015*.

(5) Based on American Community Survey 2011-2015 Journey to Work data for Census Tracts 283, 285, 287, 291, 293, 295, 299, 303 and 307.

(6) Midday and Saturday vehicle occupancy determined by applying a multiplier (1.4) to the AM/PM rate.

(7) Based on data from *Broadway Triangle FEIS*, 2009.

(8) Based on data from *The Food Retail Expansion to Support Health (FRESH) Food Store Program*, 2009.

(9) Assumes a 32% increase in peak hour trips on Saturday; based on ratio between weekday and Saturday rates for supermarket use provided by the CEQR Technical Manual, 2014.

(10) Assumes for Saturday the same temporal distribution, modal split, directional split, and vehicle occupancy as the weekday midday.

(11) Based on data from *Jamaica Plan Rezoning FGEIS, 2007*.

(12) Based on data from *No. 7 Subway Extension - Hudson Yards Rezoning and Development Program FGEIS, 2004*.

(13) Saturday rates/factors based on those for Sunday provided in the *No. 7 Subway Extension - Hudson Yards Rezoning and Development Program FGEIS*, 2004.

(14) Based on data from *Saint Vincent's Campus Redevelopment FEIS*, 2012.

(15) Assumes a student to parent ratio of 1 to 0.7 based on data from a November 2012 survey conducted at PS 35 in Queens.

(16) Parents are assumed for students in grade 5 and lower.

(17) Assumes similar modal split as that assumed for a office use.

(18) Assumes vehicle occupancy rates to be the same as those used for the Office use.

(19) Based on NYCDOT Trip Generation and Mode Choice Survey with some adjustments made per DCP and DOT recommendation.

(20) Library trip generation rates, and AM/PM/SAT MD In/Out Splits and temporal distribution based on ITE Trip Generation , Land Use 590 (Library), 9th Edition.

(21) Library modal split, vehicle occupancy, truck trip rate, truck temporal distribution, and truck IN/OUT split assumed to be similar to that of a community center.

(22) Weekday midday temporal distribution and In/Out split assumed to be similar to Saturday midday.

(23) Based on data from *East 125th Street Development FEIS, 2008*.

Figure B.7 Jerome Avenue Rezoning Travel Demand Characteristics .

Table 3: Transportation Planning Factors

Land Use	Local Retail	Regional Retail	Office	Residential	Restaurant (sit-down)	Light Industrial	Auto Repair	Auto Dealership	Warehouse
Size/Units	gsf	gsf	gsf	DU	gsf	gsf	gsf	gsf	gsf
Trip Generation	(1)	(1)	(1)	(1)	(17)	(10, 11)	(2)	(18)	(19)
Weekday	205	78.2	18	8.075	173	11.5	19.42	45.6	4.9
Saturday	240	92.5	3.9	9.6	181	1.7	19.42	28.8	1.7
	per 1,000 sf	per 1,000 sf	per 1,000 sf	per DU	per 1,000 sf	per 1,000 sf	per 1,000 sf	per 1,000 sf	per 1,000 sf
Temporal Distribution	(1)	(1)	(1)	(1)	(17)	(10, 12)	(2)	(7,18)	(9,19)
AM	3.0%	3.0%	12.0%	10.0%	0.9%	13.0%	13.2%	6.1%	8.4%
MD	19.0%	9.0%	15.0%	5.0%	6.2%	10.0%	11.0%	12.0%	14.0%
PM	10.0%	9.0%	14.0%	11.0%	8.3%	14.0%	14.2%	7.8%	8.9%
Sat MD	10.0%	11.0%	17.0%	8.0%	11.0%	10.0%	11.0%	14.1%	10.6%
Modal Splits	(2)	(4)	(4)	(5)	(17)	(4)	(2)	(7)	(4)
Auto	3.0%	37.0%	37.0%	19.3%	25.0%	37.0%	85.0%	100.0%	37.0%
Taxi	2.0%	2.0%	2.0%	1.8%	20.0%	2.0%	5.0%	0.0%	2.0%
Bus	10.0%	21.0%	21.0%	15.4%	5.0%	21.0%	1.0%	0.0%	21.0%
Subway	5.0%	21.0%	21.0%	49.2%	30.0%	21.0%	1.0%	0.0%	21.0%
Railroad	0.0%	1.0%	1.0%	2.9%	0.0%	1.0%	0.0%	0.0%	1.0%
Walk/Other	80.0%	18.0%	18.0%	11.4%	20.0%	18.0%	8.0%	0.0%	18.0%
	(2)	(3)	(2)	(2)	(2,17)	(10, 12)	(2)	(7,18)	(9,19)
In/Out Splits	In / Out	In / Out	In / Out	In / Out	In / Out	In / Out	In / Out	In / Out	In / Out
AM	50% / 50%	52% / 48%	96% / 4%	15% / 85%	94% / 6%	88% / 12%	65% / 35%	74% / 26%	79% / 21%
MD	50% / 50%	52% / 48%	39% / 61%	50% / 50%	50% / 50%	50% / 50%	50% / 50%	50% / 50%	50% / 50%
PM	50% / 50%	52% / 48%	5% / 95%	70% / 30%	67% / 33%	12% / 88%	50% / 50%	39% / 61%	25% / 75%
Sat MD	50% / 50%	52% / 48%	60% / 40%	50% / 50%	50% / 50%	50% / 50%	50% / 50%	51% / 49%	64% / 36%
				(2, 5, 6)					
Vehicle Occupancy	(2)	(3)	(2,4)	AM/PM / MD/Sat	(17)	(10)	(2)	(7)	(9,19)
Auto	1.60	2.20	1.13	1.21 / 1.69	2.20	1.65	1.30	1.30	1.30
Taxi	1.20	2.00	1.40	1.4 / 1.4	2.30	1.40	1.30	1.50	2.00
Truck Trip Generation	(1)	(3)	(1)	(1)	(17)	(10, 13)	(2)	(7)	(9)
Weekday	0.35	0.35	0.32	0.06	3.60	0.52	0.89	0.15	0.67
Saturday	0.04	0.35	0.01	0.02	3.60	0.03	0.05	0.15	0.03
Temporal Distribution	(1)	(3)	(1)	(1)	(2,17)	(10, 12)	(2)	(7)	(9)
AM	8.0%	8.0%	10.0%	12.0%	6.0%	12.0%	14.0%	9.6%	14.0%
MD	11.0%	11.0%	11.0%	9.0%	6.0%	9.0%	9.0%	11.0%	9.0%
PM	2.0%	2.0%	2.0%	2.0%	1.0%	2.0%	1.0%	1.0%	1.0%
Saturday	11.0%	11.0%	11.0%	9.0%	6.0%	9.0%	9.0%	11.0%	9.0%
In/Out Splits	In / Out	In / Out	In / Out	In / Out	In / Out	In / Out	In / Out	In / Out	In / Out
AM/MD/PM/Sat	50.0% / 50.0%	50.0% / 50.0%	50.0% / 50.0%	50.0% / 50.0%	50.0% / 50.0%	50.0% / 50.0%	50.0% / 50.0%	50.0% / 50.0%	50.0% / 50.0%

(1) Based on data from *City Environmental Quality Review (CEQR) Technical Manual*, 2014.
(2) Based on data from *Webster Avenue Rezoning EIS*, 2011.
(3) Based on data from *East Fordham Road Rezoning EIS*, 2013.
(4) RJTW based on CTTP 2006-2010 data for census tracts 197, 199, 209, 211, 213.02, 217, 219, 221.01, 223, 227.01, 227.02, 233.01, 239, 241, 243, and 251.
(5) JTW based on CTTP 2010-2014 data for census tracts 197, 199, 209, 211, 213.02, 217, 219, 221.01, 223, 227.01, 227.02, 233.01, 239, 241, 243, and 251.
(6) Midday and Saturday auto occupancy determined by applying a multiplier (1.4) to the AM/PM rate based on *East New York Rezoning EIS*, 2015.
(7) Based on data from *East New York Rezoning EIS*, 2015.
(8) Based on ITE's *Trip Generation Manual* rate for High-Turnover (Sit-Down) Restaurant (932) & Fast-Food Restaurant with Drive-Through (934).
(9) Based on data from *Lower Concourse Rezoning EIS*, 2009.
(10) *Crotona Park East / West Farms Rezoning EIS*, 2011.
(11) Saturday rate based on ITE's *Trip Generation Manual* (8th Edition) average rate proportion between weekday and Saturday
(12) Assumes weekday midday temporal distribution and in/out splits for Saturday midday.
(13) Assumes 5 percent of weekday truck trip generation rate (consistent with Lower Concourse Rezoning EIS assumptions for Manufacturing and Warehousing land uses).
(14) Assumed to be the same as Restaurant land use for *Webster Avenue Rezoning EIS*, 2011.
(15) Based on data for Covenant House from *NYCT - Number 7 Extension Project EIS*, 2003.
(16) Saturday trip rate based on ration between Saturday and weekday rates for Residential lane use. Similarly, Saturday temporal distribution based on weekday versus Saturday midday Residential proportion.
(17) Based on data from *Pier 57 Redevelopment Project EIS*, 2013.
(18) Based on ITE's *Trip Generation Manual* rate for Auto Dealership (841).
(19) Based on ITE's *Trip Generation Manual* rate for Warehousing (150).

Figure B.8 Jerome Avenue Rezoning Travel Demand Characteristics Continued.

Table 3 (continued): Transportation Planning Factors

Land Use	FRESH (Supermarket)	Pre-K (Student)	Pre-K (Staff)	Pre-K (Parent)	Day Care Center	Community Center	Medical Office (Clinic)	Gas Station (With Store)	Transitional Housing (Shelter)	House of Worship
Size/Units	esf	students	staff	parents	esf	esf	esf	esf	beds	esf
Trip Generation	(7)	(7)	(7)	(7)	(7)	(2)	(7)	(9)	(15, 16)	(7)
Weekday	205	2	2	4	33	48	127	90	4.75	19.18
Saturday	271	0	0	0	2	19	127	90	5.65	21.83
	per 1,000 sf	per student	per staff	per parent	per 1,000 sf	per 1,000 sf	per 1,000 sf	per 1,000 sf	per 1,000 sf	per 1,000 sf
Temporal Distribution	(7)	(7)	(7)	(7)	(7)	(2)	(7)	(9)	(15, 16)	(7)
AM	3.0%	50.0%	50.0%	50.0%	16.0%	7.1%	4.0%	6.2%	7.0%	7.9%
MD	12.0%	0.0%	0.0%	0.0%	5.0%	10.0%	11.0%	5.5%	3.0%	4.0%
PM	10.0%	5.0%	5.0%	5.0%	19.0%	7.2%	12.0%	8.2%	10.0%	7.2%
Sat MD	12.0%	0.0%	0.0%	0.0%	12.0%	14.2%	11.0%	5.5%	4.8%	15.8%
Modal Splits	(7)	(5)	(4)	(5)	(7)	(2)	(7)	(9)	(15)	(7)
Auto	4.0%	18.6%	37.0%	18.6%	5.0%	5.0%	30.0%	100.0%	2.0%	5.0%
Taxi	3.0%	1.6%	2.0%	1.6%	1.0%	1.0%	2.0%	0.0%	1.0%	1.0%
Bus	5.0%	15.3%	21.0%	15.3%	6.0%	6.0%	18.0%	0.0%	1.0%	3.0%
Subway	5.0%	50.7%	21.0%	50.7%	3.0%	3.0%	33.0%	0.0%	2.0%	6.0%
Railroad	0.0%	2.5%	1.0%	2.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Walk/Other	83.0%	11.3%	18.0%	11.3%	85.0%	85.0%	17.0%	0.0%	94.0%	85.0%
	(7)	(7)	(7)	(7)	(7)	(2)	(7)	(9)	(15)	(7)
In/Out Splits	In Out	In Out	In Out	In Out	In Out	In Out	In Out	In Out	In Out	In Out
AM	45% 55%	100% 0%	100% 0%	50% 50%	53% 47%	61% 39%	89% 11%	50% 50%	15% 85%	54% 46%
MD	46% 54%	0% 0%	0% 0%	0% 0%	50% 50%	55% 45%	51% 49%	50% 50%	50% 50%	50% 50%
PM	47% 53%	0% 100%	0% 100%	50% 50%	47% 53%	29% 71%	48% 52%	50% 50%	70% 30%	52% 48%
Sat MD	46% 54%	0% 0%	0% 0%	0% 0%	47% 53%	49% 51%	41% 59%	50% 50%	50% 50%	71% 29%
							(7)	(9)	(9)	(7)
Vehicle Occupancy	(7)	(5, 7)	(4, 7)		(7)	(2)	Weekday Sat	Weekday Sat	Weekday Sat	Weekday Sat
Auto	1.65	1.22	1.13	N/A	1.65	1.65	1.50 1.50	1.00 1.00	1.50 1.50	1.65 1.65
Taxi	1.40	1.30	1.40	N/A	1.40	1.40	1.50 1.50	1.00 1.00	1.50 1.50	1.40 1.40
Truck Trip Generation	(7)	(7)			(7)	(2)	(7)	(9)	(9)	(7)
Weekday	0.35	0.03	N/A	N/A	0.07	0.29	0.29	0.35	0.06	0.29
Saturday	0.04	0.03	N/A	N/A	0.00	0.01	0.29	0.02	0	0.29
Temporal Distribution	(7)	(7)			(7)	(2)	(7)	(9)	(9)	(7)
AM	10.0%	9.6%	N/A	N/A	9.6%	9.6%	3.0%	7.7%	12.2%	9.6%
MD	8.0%	11.0%	N/A	N/A	11.0%	11.0%	11.0%	11.0%	8.7%	11.0%
PM	5.0%	1.0%	N/A	N/A	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%
Saturday	10.0%	0.0%	N/A	N/A	0.0%	11.0%	0.0%	11.0%	0.0%	0.0%
In/Out Splits	In Out	In Out	In Out	In Out	In Out	In Out	In Out	In Out	In Out	In Out
AM/MD/PM/Sat	50.0% 50.0%	50.0% 50.0%	N/A N/A	N/A N/A	50.0% 50.0%	50.0% 50.0%	50.0% 50.0%	50.0% 50.0%	50.0% 50.0%	50.0% 50.0%

(1) Based on data from *City Environmental Quality Review (CEQR) Technical Manual*, 2014.
(2) Based on data from *Webster Avenue Rezoning EIS*, 2011.
(3) Based on data from *East Fordham Road Rezoning EIS*, 2013.
(4) RJTW based on CTTP 2006-2010 data for census tracts 197, 199, 209, 211, 213.02, 217, 219, 221.01, 223, 227.01, 227.02, 233.01, 239, 241, 243, and
(5) JTW based on CTTP 2010-2014 data for census tracts 197, 199, 209, 211, 213.02, 217, 219, 221.01, 223, 227.01, 227.02, 233.01, 239, 241, 243, and 251.
(6) Midday and Saturday auto occupancy determined by applying a multiplier (1.4) to the AM/PM rate based on *East New York Rezoning EIS*,
(7) Based on data from *East New York Rezoning EIS*, 2015.
(8) Based on ITE's *Trip Generation Manual* rate for High-Turnover (Sit-Down) Restaurant (932) & Fast-Food Restaurant with Drive-Through (934).
(9) Based on data from *Lower Concourse Rezoning EIS*, 2009.
(10) *Crotona Park East / West Farms Rezoning EIS*, 2011.
(11) Saturday rate based on ITE's *Trip Generation Manual* (8th Edition) average rate proportion between weekday and
(12) Assumes weekday midday temporal distribution and in/out splits for Saturday
(13) Assumes 5 percent of weekday truck trip generation rate (consistent with Lower Concourse Rezoning EIS assumptions for Manufacturing and Warehousing land
(14) Assumed to be the same as Restaurant land use for *Webster Avenue Rezoning EIS*, 2011.
(15) Based on data for Covenant House from *NYCT - Number 7 Extension Project EIS*, 2003.
(16) Saturday trip rate based on ration between Saturday and weekday rates for Residential lane use. Similarly, Saturday temporal distribution based on weekday versus Saturday midday Residential
(17) Based on data from *Pier 57 Redevelopment Project EIS*, 2013.
(18) Based on ITE's *Trip Generation Manual* rate for Auto Dealership (841).
(19) Based on ITE's *Trip Generation Manual* rate for Warehousing (150).

Figure B.9 La Central Rezoning Travel Demand Characteristics.

TABLE 3-3
Transportation Planning Factors

Land Use:	Residential		Local Retail		Health Club (YMCA)		Office (Common Ground)		Day Care		Community Facility (Recreation) (Rooftop Garden/Other)		TV Studio		Music Studio Rehearsal	
Size/Units:	992	DU	34,100	gsf	50,500	gsf	7,300	gsf	8,300	gsf	6,800	gsf	12,700	gsf	8,600	gsf
															102	seats
Trip Generation:	(1)		(1)		(1)		(1)		(9)		(3)		(1,10)		(11)	
Weekday	8.075		205		44.7		18		33		44.7		10		27	per 1,000 sf
Saturday	9.6		240		26.1		3.9		2		26.6		10		2.68	per seat
	per DU		per 1,000 sf		per 1,000 sf		per 1,000 sf		per 1,000 sf		per 1,000 sf		per 1,000 sf			
Temporal Distribution:	(1)		(1)		(1)		(1)		(9)		(3)		(1,10)		(11)	
AM	10.0%		3.0%		4.0%		12.0%		16.0%		5.8%		12.0%		1.0%	
MD	5.0%		19.0%		9.0%		15.0%		5.0%		7.4%		15.0%		16.0%	
PM	11.0%		10.0%		5.0%		14.0%		19.0%		7.6%		11.0%		13.0%	
Sat MD	8.0%		10.0%		9.0%		17.0%		12.0%		10.0%		15.0%		10.0%	
	(2)		(4)		(4)		(8,4)		(2)		(3)		(8,4)		(11)	
Modal Splits:	ALL PERIODS		ALL PERIODS		ALL PERIODS		AM/PM/SAT	MD	ALL PERIODS		ALL PERIODS		AM/PM/SAT	MD	ALL PERIODS	
Auto	6.8%		2.0%		4.0%		35.9%	10.0%	6.8%		4.0%		35.9%	10.0%	19.5%	
Taxi	3.8%		3.0%		9.0%		0.0%	2.0%	3.8%		9.0%		0.0%	2.0%	10.0%	
Subway	51.9%		6.0%		12.0%		22.1%	5.0%	51.9%		12.0%		22.1%	5.0%	20.0%	
Bus	13.3%		6.0%		5.0%		20.3%	5.0%	13.3%		5.0%		20.3%	5.0%	20.0%	
Walk	24.2%		83.0%		70.0%		21.7%	78.0%	24.2%		70.0%		21.7%	78.0%	30.5%	
	100.0%		100.0%		100.0%		100.0%	100.0%	100.0%		100.0%		100.0%	100.0%	100.0%	
	(3)		(4)		(5)		(4)		(9)		(3)		(4)		(11)	
In/Out Splits:	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
AM	15%	85%	50%	50%	60%	40%	94%	6%	53%	47%	66%	34%	94%	6%	61%	39%
MD	50%	50%	50%	50%	53%	47%	50%	50%	50%	50%	58%	42%	50%	50%	55%	45%
PM	70%	30%	50%	50%	50%	50%	5%	95%	47%	53%	34%	66%	5%	95%	29%	71%
Sat MD	53%	47%	50%	50%	34%	66%	60%	40%	47%	53%	58%	42%	60%	40%	0%	100%
															(11)	
Vehicle Occupancy:	(2,3)		(3)		(4)		(8)		(9)		(3)		(8)		Weekday	Weekend
Auto	1.05		2.00		1.40		1.05		1.65		1.40		1.05		1.60	2.90
Taxi	1.40		2.00		1.40		1.05		1.40		1.40		1.05		1.20	2.30
Truck Trip Generation:	(1)		(1)		(4)		(1)		(9)		(3)		(1)		(11)	
Weekday	0.06		0.35		0.04		0.32		0.07		0.04		0.32		0.14	
Saturday	0.02		0.04		0.04		0.01		0.00		0.01		0.01		0.01	
	per DU		per 1,000 sf		per 1,000 sf		per 1,000 sf		per 1,000 sf		per 1,000 sf		per 1,000 sf		per 1,000 sf	
	(1)		(1)		(4)		(1)		(9)		(3)		(1)		(11)	
AM	12.0%		8.0%		8.0%		10.0%		9.6%		7.7%		10.0%		10.0%	
MD	9.0%		11.0%		11.0%		11.0%		11.0%		11.0%		11.0%		11.0%	
PM	2.0%		2.0%		1.0%		2.0%		1.0%		2.0%		2.0%		2.0%	
Sat MD	9.0%		11.0%		0.0%		11.0%		0.0%		11.0%		11.0%		11.0%	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
All Peak Hours	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%

Notes:

(1) 2014 CEQR Technical Manual.
(2) Based on 2008-2012 American Community Survey (ACS) Tenure Data for Bronx Census Tract 71.
(3) West Harlem Rezoning FEIS, August 2012.
(4) Triangle Plaza Hub EAS, January 2012.
(5) Based on March 2014 data provided by Chinatown YMCA facility.
(6) Based on data provided by NYCDOT.
(7) Jamaica Plan Rezoning FEIS, June 2007.
(8) 2006-2010 AASHTO Reverse Journey to Work Data for Bronx Census Tract 71.
(9) No. 7 Subway Extension - Hudson Yards Rezoning and Development Program FGEIS, 2004.
(10) Saturday daily trip rate and temporal distribution assumed to be the same as weekday.
(11) Melrose Commons North EAS, 2014.

Figure B.10 Silvercup West Travel Demand Characteristics.

TABLE 9-14: WEEKDAY TRAVEL DEMAND CHARACTERISTICS

	Office	Health Club	Residential	Studio	Retail	Museum
	655,048 sf	40,013 sf	1,000 DU	346,881 sf	76,581 sf Street Level	126,401 sf
Person Trip Gen Rate	18.0[6] *per 1,000 SF*	82.0[12] *per 1,000 SF*	4.2[4] *per DU*	10.0[6] *per 1,000 SF*	205.0[5] *per 1,000 SF*	27.4[3] *per 1,000 SF*
Temporal Distribution						
AM Peak	14.4%[5]	4.0%[12]	10.5%[5]	11.8%[6]	0.0%[5]	0.0%[3]
Midday Peak	8.7%[5]	5.0%[12]	2.2%[5]	15.0%[6]	8.7%[5]	9.4%[3]
PM Peak	11.1%[5]	8.0%[12]	8.7%[5]	10.3%[6]	8.0%[5]	14.4%[3]
Linked Trip Credit	0.0%	0.0%	0.0%	0.0%	10.0%	0.0%
Modal Split (Weekday AM)						
Auto	17.0%[5]	17.6%[12]	24.0%[5]	17.0%[9]	2.0%[5]	70.0%[10]
Taxi	1.0%[5]	1.0%[12]	1.0%[5]	1.0%[9]	3.0%[5]	5.0%[10]
Bus	4.0%[5]	4.7%[12]	3.0%[5]	4.0%[9]	10.0%[5]	5.0%[10]
Subway	58.0%[5]	8.6%[12]	54.0%[5]	58.0%[9]	10.0%[5]	10.0%[10]
Walk	10.0%[5]	68.1%[12]	18.0%[5]	10.0%[9]	75.0%[5]	10.0%[10]
LIRR	10.0%[5]	0.0%[12]	0.0%[5]	10.0%[9]	0.0%[5]	0.0%[10]
Modal Split (Weekday Midday)						
Auto	6.5%[5]	15.8%[12]	24.0%[5]	6.5%[9]	2.0%[5]	70.0%[10]
Taxi	2.0%[5]	1.0%[12]	1.0%[5]	2.0%[9]	3.0%[5]	5.0%[10]
Bus	0.0%[5]	4.9%[12]	3.0%[5]	0.0%[9]	10.0%[5]	5.0%[10]
Subway	36.0%[5]	9.9%[12]	54.0%[5]	36.0%[9]	10.0%[5]	10.0%[10]
Walk	55.5%[5]	68.4%[12]	18.0%[5]	55.5%[9]	75.0%[5]	10.0%[10]
LIRR	0.0%[5]	0.0%[12]	0.0%[5]	0.0%[9]	0.0%[5]	0.0%[10]
Modal Split (Weekday PM)						
Auto	17.0%[5]	12.7%[12]	24.0%[5]	17.0%[9]	2.0%[5]	70.0%[10]
Taxi	1.0%[5]	1.0%[12]	1.0%[5]	1.0%[9]	3.0%[5]	5.0%[10]
Bus	4.0%[5]	3.8%[12]	3.0%[5]	4.0%[9]	10.0%[5]	5.0%[10]
Subway	58.0%[5]	12.8%[12]	54.0%[5]	58.0%[9]	10.0%[5]	10.0%[10]
Walk	10.0%[5]	69.7%[12]	18.0% [5]	10.0%[9]	75.0%[5]	10.0%[10]
LIRR	10.0%[5]	0.0%[12]	0.0%[5]	10.0%[9]	0.0%[5]	0.0%[10]
Vehicle Occupancy (Weekday)						
Auto	1.65[5]	1.15[7]	1.65[5]	1.65[9]	1.65[5]	2.34[3]
Taxi	1.40[5]	1.40[12]	1.40[5]	1.40[9]	1.40[5]	1.90[3]
Truck Trip Gen	0.20[2] *per 1,000 SF*	0.04[5] *per 1,000 SF*	0.06[5] *per DU*	0.04[8] *per 1,000 SF*	0.35[8] *per 1,000 SF*	0.05[3] *per 1,000 SF*
Truck Temporal Distribution						
AM Peak	9.7%[1]	0.0%	9.7%[5]	25.0%[8]	9.7%[1]	9.7%[11]
Midday Peak	7.8%[1]	0.0%	7.8%[5]	8.0%[8]	7.8%[1]	7.8%[11]
PM Peak	5.1%[1]	0.0%	5.1%[5]	3.0%[8]	5.1%[1]	5.1%[11]

Note: For Catering Hall trip generation, please refer to the description on page 9-36.

1. *Motor Trucks in the Metropolis*, 1969, Wilbur Smith and Associates
2. Urban Truck Road Systems and Travel Restrictions, 1975, Wilbur Smith and Associates
3. *MoMA FEIS*, October 6, 2000
4. ITE Trip Generation (High-rise Residential Condo/Townhouse - Land Use 232).
5. *Long Island City Rezoning FEIS*, 2001
6. *CEQR Technical Manual*
7. 1990 Census Journey to Work
8. *ABC West End Avenue Properties FEIS*, March 1993
9. Assumed similar to Office use
10. *Comparable to East River Plaza FEIS*, August 19, 1999
11. Assume same as retail
12. Survey of Vertical Club in Manhattan, 1992, EWT (modal splits slightly modified – "other" was combined with "auto" and "taxi" was reduced to 1% with the remaining "taxi" converted to "auto").

Figure B.11 New Stapleton Waterfront Redevelopment Travel Demand Characteristics.

Weekday Travel Demand Characteristics
Build Condition

	Residential 667,500 SF 638 DU	**Office 75,000 SF**	**Sports Complex 75,000 SF**	**Restaurant 18,000 SF**	**Open Space 12 acres**	**Local Retail 83,700 SF**
Person Trip Gen Rate	8.1[2]	18.0[2]	30.0[9]	173.0[2]	61.0[9]	205.0[2]
	per DU	per 1,000 SF	per 1,000 SF	per 1,000 SF	per acre	per 1,000 SF
Temporal Distribution						
AM Peak	9.1%[2]	11.8%[2]	3.9%[9]	1.0%[2]	6.0%[9]	1.0%[2]
Midday Peak	4.7%[2]	15.0%[2]	6.5%[9]	17.7%[2]	15.0%[12]	12.0%[10]
PM Peak	10.7%[2]	13.7%[2]	9.1%[9]	7.7%[2]	10.0%[9]	9.6%[2]
Linked Trip Credit	0.0%	0.0%	0.0%	0.0%	30.0%	25.0%
Modal Split (Weekday AM)						
Auto	52.0%[1]	61.4%[1]	68.2%[7]	80.0%[7]	15.0%[11]	9.0%[5]
Taxi	0.5%[1]	0.5%[1]	2.0%[7]	2.0%[7]	0.0%[11]	2.0%[5]
Bus	29.1%[1]	14.0%[1]	12.5%[7]	6.0%[7]	2.5%[11]	7.0%[5]
SIR	8.4%[1]	19.3%[1]	8.3%[7]	4.0%[7]	2.5%[11]	7.0%[5]
Walk	10.0%[1]	4.8%[1]	9.0%[7]	8.0%[7]	80.0%[11]	75.0%[5]
Modal Split (Weekday midday)						
Auto	37.0%[1]	56.4%[1]	68.2%[7]	80.0%[7]	15.0%[11]	9.0%[5]
Taxi	0.5%[1]	0.5%[1]	2.0%[7]	2.0%[7]	0.0%[11]	2.0%[5]
Bus	29.1%[1]	3.6%[1]	12.5%[7]	6.0%[7]	2.5%[11]	7.0%[5]
SIR	8.4%[1]	8.5%[1]	8.3%[7]	4.0%[7]	2.5%[11]	7.0%[5]
Walk	25.0%[1]	31.0%[1]	9.0%[7]	8.0%[7]	80.0%[11]	75.0%[5]
Modal Split (Weekday PM)						
Auto	52.0%[1]	61.4%[1]	68.2%[7]	80.0%[7]	15.0%[11]	9.0%[5]
Taxi	0.5%[1]	0.5%[1]	2.0%[7]	2.0%[7]	0.0%[11]	2.0%[5]
Bus	29.1%[1]	14.0%[1]	12.5%[7]	6.0%[7]	2.5%[11]	7.0%[5]
SIR	8.4%[1]	19.3%[1]	8.3%[7]	4.0%[7]	2.5%[11]	7.0%[5]
Walk	10.0%[1]	4.8%[1]	9.0%[7]	8.0%[7]	80.0%[11]	75.0%[5]
Vehicle Occupancy (Weekday)						
Auto	1.13[1]	1.10[1]	2.00[7]	2.00[7]	2.80[9]	1.65[5]
Taxi	1.40[5]	1.40[5]	2.00[7]	2.00[7]	1.40[9]	1.40[5]
Directional Split (Ins)						
AM Peak	16.0%[5]	93.0%[5]	41.0%[9]	82.0%[8]	80.0%[9]	50.0%
Midday Peak	59.0%[5]	46.0%[5]	50.0%[9]	50.0%[8]	65.0%[13]	50.0%
PM Peak	75.0%[5]	3.0%[5]	75.0%[9]	67.0%[8]	45.0%[9]	50.0%
Truck Trip Gen	0.06[5]	0.20[4]	0.04[9]	0.79[8]	-	0.35[6]
	per DU	per 1,000 SF	per 1,000 SF	per 1,000 SF	-	per 1,000 SF
Truck Temporal Distribution						
AM Peak	9.7%[3]	9.7%[3]	9.7%[3]	9.7%[3]	-	9.7%[3]
Midday Peak	7.8%[3]	7.8%[3]	7.8%[3]	7.8%[3]	-	7.8%[3]
PM Peak	5.1%[3]	5.1%[3]	5.1%[3]	5.1%[3]	-	5.1%[3]
Truck Trip Directional Split (Ins)						
AM Peak	50.0%	50.0%	50.0%	50.0%	-	50.0%
Midday Peak	50.0%	50.0%	50.0%	50.0%	-	50.0%
PM Peak	50.0%	50.0%	50.0%	50.0%	-	50.0%

Trip Generation References

1. 2000 Census Transportation Planning Package (CTPP)
2. CEQR Technical Manual
3. Motor Trucks in the Metropolis, 1969, Wilbur Smith and Associates
4. Urban Truck Road Systems and Travel Restrictions, Wilbur Smith and Associates, 1975
5. Long Island City Rezoning FEIS, 2001
6. ABC West End Avenue Properties FEIS, March 1993
7. East River Plaza EIS (2001) - Destination Retail
8. ITE Trip Generation Manual (Quality Restaurant)
9. Chelsea Piers FEIS, 1993
10. CEQR Technical Manual – Modified as explained in text
11. Chelsea Piers FEIS, 1993 - Slightly modified to reflect Stapleton conditions.
12. Assumed the average of Saturday midday and weekday PM
13. Assume similar to Saturday midday

Figure B.12 Western Rail Yards Travel Demand Characteristics.

Table 2A:
Transportation Planning Factors

Land Use:	Residential		Office		Local Retail		Destination Retail	
Trip Generation:	(1)	(2)	(6)	(8)	(10,11)	(12,11)	(6) (11)	(13) (11)
	Weekday	**Saturday**	**Weekday**	**Saturday**	**Weekday**	**Saturday**	**Weekday**	**Saturday**
Daily Person Trips	8.075	9.57	18.0	3.87	205	240	159	185
Net Daily Person Trips	8.075	9.57	18.0	3.87	154	180	119	139
	per dwelling unit		per 1,000 gsf		per 1,000 gsf		per 1,000 gsf	
Temporal Distribution:	(1,3)		(1,14)		(6,7)		(6,13)	
AM (8-9)	9.1%		11.8%		3.1%		0.0%	
MD (12-1)	4.7%		15.0%		19.0%		9.5%	
PM (5-6)	10.7%		13.7%		9.6%		9.8%	
SAT (1-2)	7.0%		15.0%		9.5%		9.9%	
In/Out Splits:	(1,3)		(1,14)		(6)		(6,13)	
	In	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**
AM (8-9)	15%	85%	96%	4%	50%	50%	0%	0%
MD (12-1)	50%	50%	48%	52%	50%	50%	55%	45%
PM (5-6)	70%	30%	5%	95%	50%	50%	47%	53%
SAT (1-2)	50%	50%	57%	43%	50%	50%	52%	48%
Modal Splits:	(4)		(9)	(6)	(6)		(3,6)	
	All		**AM/PM**	**MD/SAT**	**All**		**PM**	**MD/SAT**
Auto	6.6%		9.9%	2.0%	2.0%		9.0%	9.0%
Taxi	6.5%		2.4%	3.0%	3.0%		4.0%	4.0%
Bus	5.8%		15.8%	6.0%	6.0%		8.0%	8.0%
Subway	37.5%		43.7%	6.0%	6.0%		26.5%	20.0%
Railroad	2.0%		20.1%	0.0%	0.0%		2.0%	0.0%
Walk	40.3%		7.2%	83.0%	83.0%		50.5%	59.0%
Other	1.3%		0.3%	0.0%	0.0%		0.0%	0.0%
Work at Home	0.0%		0.6%	0.0%	0.0%		0.0%	0.0%
	100.0%		100.0%	100.0%	100.0%		100.0%	100.0%
Vehicle Occupancy:	(6)		(6)		(6)		(6)	
Auto	1.65		1.65		1.65		2.00	
Taxi	1.40		1.40		1.40		2.00	
Truck Trip Generation:	(6)	(7)	(6)	(7)	(6)	(7)	(6)	(15)
	Weekday	**Saturday**	**Weekday**	**Saturday**	**Weekday**	**Saturday**	**Weekday**	**Saturday**
	0.03	0.01	0.16	0.01	0.35	0.02	0.35	0.02
	per dwelling unit		per 1,000 gsf		per 1,000 gsf		per 1,000 gsf	
	(6,7)		(7)		(6,7)		(6,15)	
AM (8-9)	12.2%		7.0%		7.7%		7.7%	
MD (12-1)	8.7%		7.0%		11.0%		11.0%	
PM (5-6)	2.0%		3.0%		1.0%		1.0%	
SAT (1-2)	9.0%		11.0%		11.0%		11.0%	
	In	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**
	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%

Sources:

(1) Pushkarev & Zupan, "Urban Space for Pedestrians," 1975.
(2) ITE Trip Generation, 7th Edition, Land Use Code 220: High Rise Apartment Ratio of Weekday to Saturday Trip Generation Rates
(3) Farley/Moynihan West FEIS, 2006, Table 13-1
(4) Hudson Yards FGEIS, Appendix S-1 Based Upon 2000 US Census Journey-to-Work "Residence of Worker" data
(5) Assumes approximately 8.3 students per staff based upon Hudson Yards FGEIS, Appendix S-1
(6) No. 7 Subway Extension - Hudson Yards Rezoning and Development Program FGEIS, 2004.
(7) Atlantic Yards and Arena Redevelopment FEIS, 2006
(8) ITE Trip Generation, 7th Edition, Land Use Code 710: General Office Building Ratio of Weekday to Saturday Trip Generation Rates
(9) Hudson Yards FGEIS, Appendix S-1 Updated by NYCDCP, NYCDOT and NYCT Working Group
(10) City Environmental Quality Review (CEQR) Technical Manual, Appendix 3, 2001
(11) Assumes 25% linked trips for retail uses as per No. 7 Subway Extension - Hudson Yards Rezoning and Development Program FGEIS, 2004.
(12) ITE Trip Generation, 7th Edition, Land Use Code 851: Convenience Retail Ratio of Weekday to Saturday Trip Generation Rates
(13) ITE Trip Generation, 7th Edition, Land Use Code 820: Shopping Center Ratio of Weekday to Saturday Trip Generation Rates
Directional distribution based upon Saturday peak hour of the generator
(14) ITE Trip Generation, 7th Edition, Land Use Code 710: General Office Building Ratio of Saturday Peak Hour Trip Generation Rate to Saturday Daily Rate.
Directional distribution based upon Saturday peak hour of the generator
(15) Assumes same Saturday truck trip generation rate as local retail.
(16) Hotel Saturday trip generation rate assumed same as weekday as per NYCDOT 3-14-08, Expanded Moynihan/Penn Station Redevelopment Project
(17) Survey conducted as part of PS 59 Expansion, March 2007. To be used as per NYCDOT directive 11-5-08
(18) NYCDOT directive 11-5-08
(19) Curbside Pickup & Delivery Operations & Arterial Traffic Impacts, FHWA, February, 1981.
(20) Adult accompanying children walking to and from school based upon 88 per cent walk share and one parent per two children
(21) Adopted and modified from PS/IS at 268-284 Dyckman Street, Manhattan, 2004
(22) As per the Hudson Yards FGEIS, for hotels adjacent to the Jacob K. Javits Convention Center, 2 daily person trips per room
are assumed to be linked walk trips between the Convention Center and the hotel.

Figure B.13 Western Rail Yards Travel Demand Characteristics Continued.

Table 2B:
Transportation Planning Factors

Land Use:	Hotel		Elementary School (Students)		Elementary School (Parents)		Intermediate School (Students)		School (Staff)	
Trip Generation:	(6,16,22)		(17)		(6, 20)		(21)		(5, 6)	
	Weekday	Saturday	Weekday	Saturday	Weekday	Saturday	Weekday	Saturday	Weekday	Saturday
Daily Person Trips	9.42	9.42	2	0.0	1.8	0.0	2	0.0	2.0	0.0
Net Daily Person Trips	7.42	7.42	2	0.0	1.8	0.0	2	0.0	2.0	0.0
	per room		per student		per student		per student		per employee	
Temporal Distribution:	(3,6)		(6)		(6)		(6)		(6)	
AM (8-9)	7.5%		50.0%		50.0%		50.0%		5.0%	
MD (12-1)	14.4%		0.0%		0.0%		0.0%		0.0%	
PM (5-6)	12.8%		2.5%		2.5%		2.5%		2.5%	
SAT (1-2)	7.5%		0.0%		0.0%		0.0%		0.0%	
In/Out Splits:	(3,6)		(6)		(6)		(6)		(6)	
	In	Out	In	Out	In	Out	In	Out	In	Out
AM (8-9)	39%	61%	100%	0%	100%	100%	100%	0%	100%	0%
MD (12-1)	54%	46%	50%	50%	100%	100%	50%	50%	50%	50%
PM (5-6)	65%	35%	0%	100%	100%	100%	0%	100%	0%	100%
SAT (1-2)	56%	44%	0%	0%	0%	0%	0%	0%	0%	0%
Modal Splits:	(3,6)	(6)	(17)		(6)		(21)		(9)	(6)
	AM/PM/SAT	MIDDAY	AM/MD/PM		AM/MD/PM		AM/MD/PM		AM/PM	MIDDAY
Auto	9.0%	8.0%	6.2%		0%		0%		9.9%	2.0%
Taxi	18.0%	15.0%	1.7%		0%		0%		2.4%	3.0%
Bus	3.0%	3.0%	0.0%		0%		40%		15.8%	6.0%
Subway	24.0%	13.0%	0.0%		0%		15%		43.7%	6.0%
Railroad	0.0%	0.0%	0.0%		0%		0%		20.1%	0.0%
Walk	46.0%	61.0%	88.2%		100.0%		45.0%		7.2%	83.0%
Other (School Bus)	0.0%	0.0%	3.9%		0.0%		0.0%		0.9%	0.0%
Work at Home	0.0%	0.0%	0.0%		0.0%		0.0%		0.0%	0.0%
	100.0%	100.0%	100.0%		100.0%		100.0%		100.0%	100.0%
Vehicle Occupancy:	(6)		(17,18)						(17)	
Auto	1.40		1.74		NA		NA		1.20	
Taxi	1.80		1.40		NA		NA		1.40	
Truck Trip Generation:	(6)	(19)							(6)	
	Weekday	Saturday							Weekday	Saturday
	0.06	0.01							0.03	0.00
	per 1,000 gsf								per 1,000 gsf	
	(6,19)								(6)	
AM (8-9)	12.2%								9.6%	
MD (12-1)	8.7%								11.0%	
PM (5-6)	1.0%								1.0%	
SAT (1-2)	9.0%								0.0%	
	In	Out							In	Out
	50.0%	50.0%							50.0%	50.0%

Sources:

(1) Pushkarev & Zupan, "Urban Space for Pedestrians," 1975.
(2) ITE Trip Generation, 7th Edition, Land Use Code 220: High Rise Apartment Ratio of Weekday to Saturday Trip Generation Rates
(3) Farley/Moynihan West FEIS, 2006, Table 13-1
(4) Hudson Yards FGEIS, Appendix S-1 Based Upon 2000 US Census Journey-to-Work "Residence of Worker" data
(5) Assumes approximately 8.3 students per staff based upon Hudson Yards FGEIS, Appendix S-1
(6) No. 7 Subway Extension - Hudson Yards Rezoning and Development Program FGEIS, 2004.
(7) Atlantic Yards and Arena Redevelopment FEIS, 2006
(8) ITE Trip Generation, 7th Edition, Land Use Code 710: General Office Building Ratio of Weekday to Saturday Trip Generation Rates
(9) Hudson Yards FGEIS, Appendix S-1 Updated by NYCDCP, NYCDOT and NYCT Working Group
(10) City Environmental Quality Review (CEQR) Technical Manual, Appendix 3, 2001
(11) Assumes 25% linked trips for retail uses as per No. 7 Subway Extension - Hudson Yards Rezoning and Development Program FGEIS, 2004.
(12) ITE Trip Generation, 7th Edition, Land Use Code 851: Convenience Retail Ratio of Weekday to Saturday Trip Generation Rates
(13) ITE Trip Generation, 7th Edition, Land Use Code 820: Shopping Center Ratio of Weekday to Saturday Trip Generation Rates
Directional distribution based upon Saturday peak hour of the generator
(14) ITE Trip Generation, 7th Edition, Land Use Code 710: General Office Building Ratio of Saturday Peak Hour Trip Generation Rate to Saturday Daily Rate.
Directional distribution based upon Saturday peak hour of the generator
(15) Assumes same Saturday truck trip generation rate as local retail.
(16) Hotel Saturday trip generation rate assumed same as weekday as per NYCDOT 3-14-08, Expanded Moynihan/Penn Station Redevelopment Project
(17) Survey conducted as part of PS 59 Expansion, March 2007. To be used as per NYCDOT directive 11-5-08
(18) NYCDOT directive 11-5-08
(19) Curbside Pickup & Delivery Operations & Arterial Traffic Impacts, FHWA, February, 1981.
(20) Adult accompanying children walking to and from school based upon 88 per cent walk share and one parent per two children
(21) Adopted and modified from PS/IS at 268-284 Dyckman Street, Manhattan, 2004
(22) As per the Hudson Yards FGEIS, for hotels adjacent to the Jacob K. Javits Convention Center, 2 daily person trips per room
are assumed to be linked walk trips between the Convention Center and the hotel.

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